Attitude Determination & Control System

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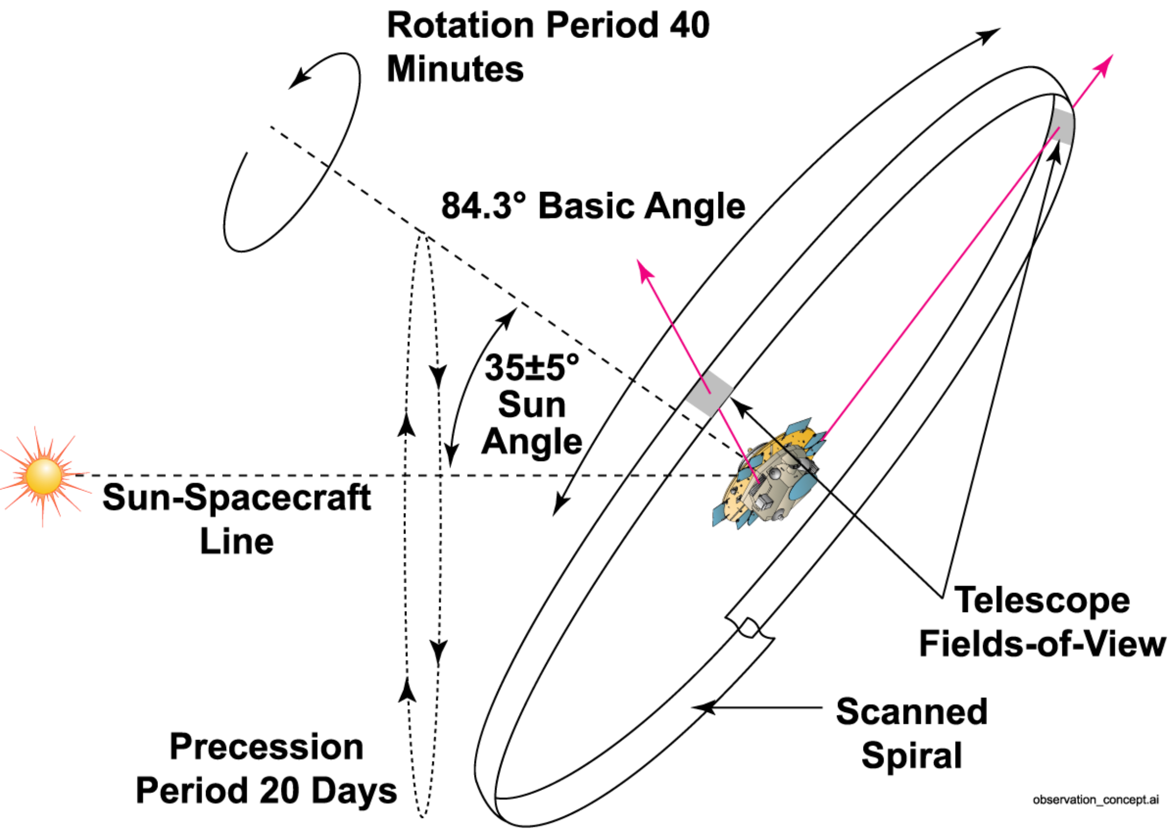
PDR Topics

- Top Level Requirements
- Preliminary Design Description
  - Baseline Summary
  - Trades
  - Hardware Block Diagram & FAME Views
  - Solar Precession
  - Software Modes
  - Sensor Processing
  - Attitude Control
- Component Summary
- Propellant, Mass, & Power Summary
- Test & Verification Plan
- Milestones
- Open Issues

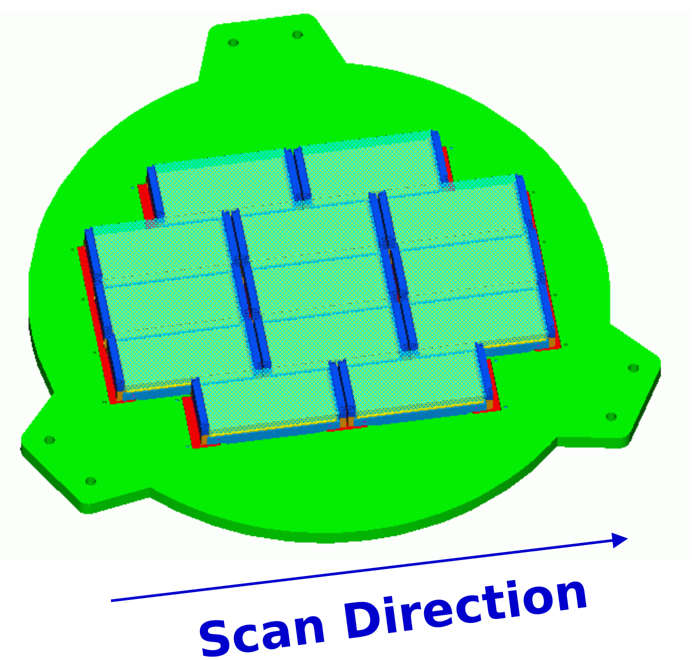
Back-Up Materials

- Subsystem Requirements
  - Top Level Requirement Flow-Down to ADCS & Other Subsystems
  - Derived Requirements
- Solar Precession, Spin Rate Control, Nutation Angle Control, Sun Angle Control
  - Concept, Block Diagram, Analysis Results, Simulation Results, Sensor Measurements

Graphical Aids



Focal Plane Assembly with 13 CCDs



Top Level System Requirements (1 of 2)

- Mission Duration of 5 Years @ Geosynchronous Orbit [From MRD]
- Spacecraft Observing Parameter Requirements [From MRD]
  - Spin Period: 40 +/- 4 Min (2.62 +/- 0.262 mrad/sec)
  - Precession Period: 20 +/- 2 Days
  - Sun Angle: 35 +/- 5 Deg
- Science Collection Requirements [From MRD]
  - See Slide (2 of 2)
- Acquisition Mode Requirements (600 X 600 Pixel Acquisition Window) [From MRD]
  - Attitude Knowledge: 250 μrad/axis (3σ) (Derived)
- Mission Support [From MRD]
  - Orbit Adjustment
    - AKM Burn for Transfer From GEO Transfer Orbit Into GEO Orbit
    - Orbit Correction Burn(s) to Get Into Final GEO Orbit
  - Instrument/spacecraft Protection
  - Disposal Capability at End of Mission

Top Level System Requirements (2 of 2)

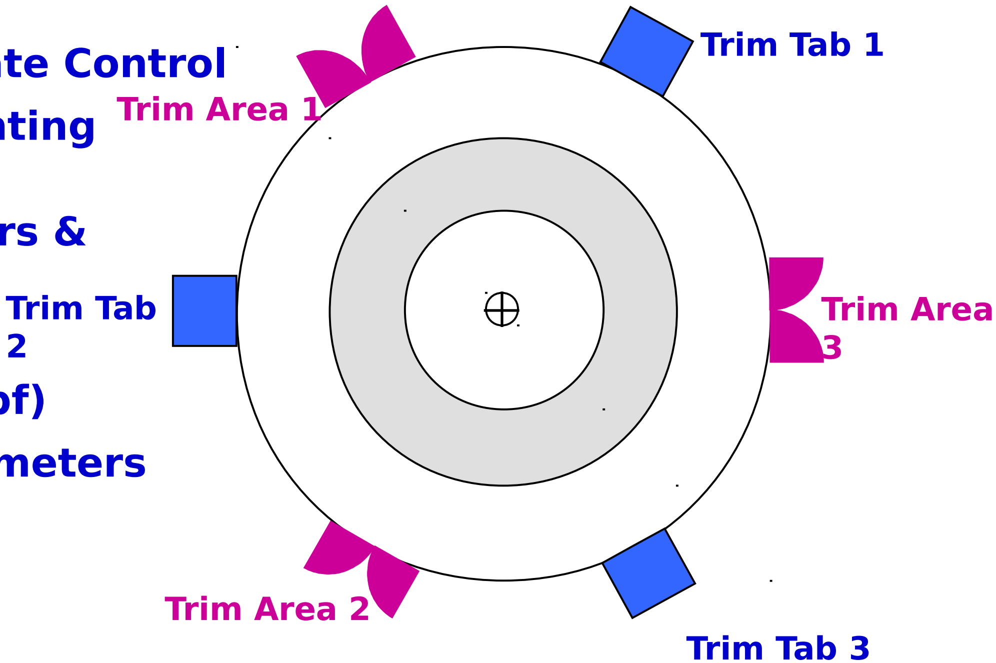
- Science Collection Requirements
  - All Vehicle Motion Must Be Either Modelable or Less Than Jitter Allocations
  - Astrometric Mission Along Scan Requirements [From MRD]
    - Modelable Spin Rate Variations: +/- 0.262 μrad/sec in 300 sec
    - Unmodelable Variations (Jitter):
  - Astrometric Mission Cross Scan Requirements [From MRD]
    - Modelable Disturbances: 6.5 Pixels in 2.03 sec
      - Nominal Solar Precession: 3.6 Pixels
      - Other Modelable Disturbances: 2.9 Pixels
    - Unmodelable Variations (Jitter):
  - Astrometric Mission Requirement: [From MRD]
    - Misalignment of Principal Spin Axis to Instrument Spin Axis: 150 μrad

Frequency (Hz): 0.2 1.0 10
100
Amplitude (μrad): 0.01 0.001
0.003 0.01

Frequency (Hz): 0.2 1.0 10
100
Amplitude (μrad): 0.1 0.025
0.03 0.1

ADCS PDR Baseline

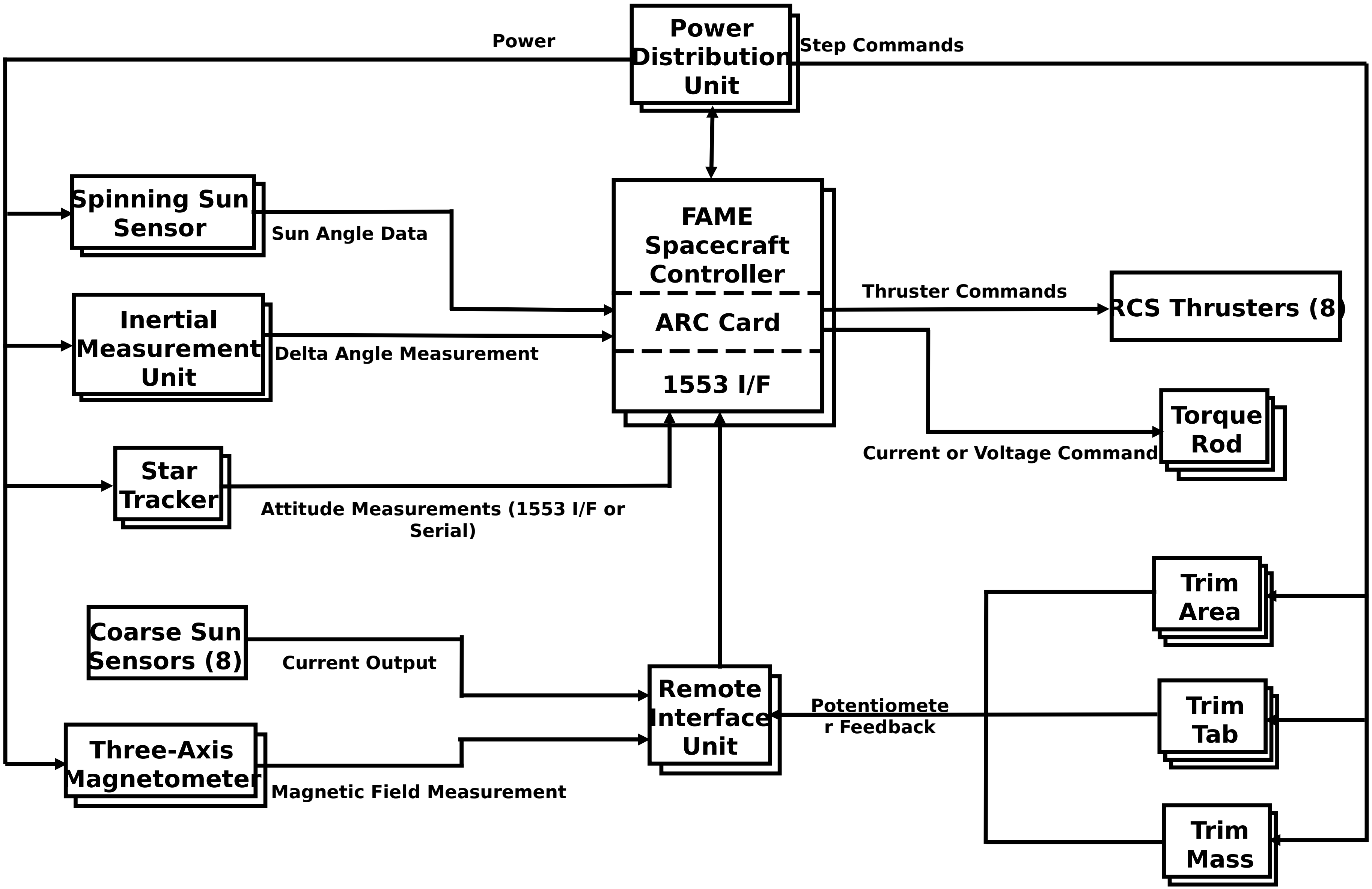
- Solar Precession & Passive Operation For Science Data Collection
  - Fixed Sun Shield/Solar Panel With Zero Sweep Angle
- On-Orbit Balance Adjustment Capability
  - Three Trim Tabs for Solar Radiation Torque Adjustment
  - Three Trim Areas for CP-to-CM Balancing
  - Two Trim Masses for Principal Axis Misalignment Control
- Fine Acquisition of Instrument Pointing Control With Electromagnetic Torquers (EMTs)
  - Z-Axis EMT for Active Nutation Damping, Precession Rate Control, & Sun Angle Control
  - X- & Y-Axis EMTs for Active Spin Rate Control
- Coarse Acquisition of Instrument Pointing Control With Thrusters
- Attitude Knowledge From Star Trackers & Inertial Measurement Units (IMU)
- Spinning Modes to Support AKM Burn
- Eight Thrusters (Two 5-lbf & Six 0.2-lbf)
- Three EMTs, Two Three-Axis Magnetometers
- 20 kg ACS Propellant
- No Star Tracker Covers



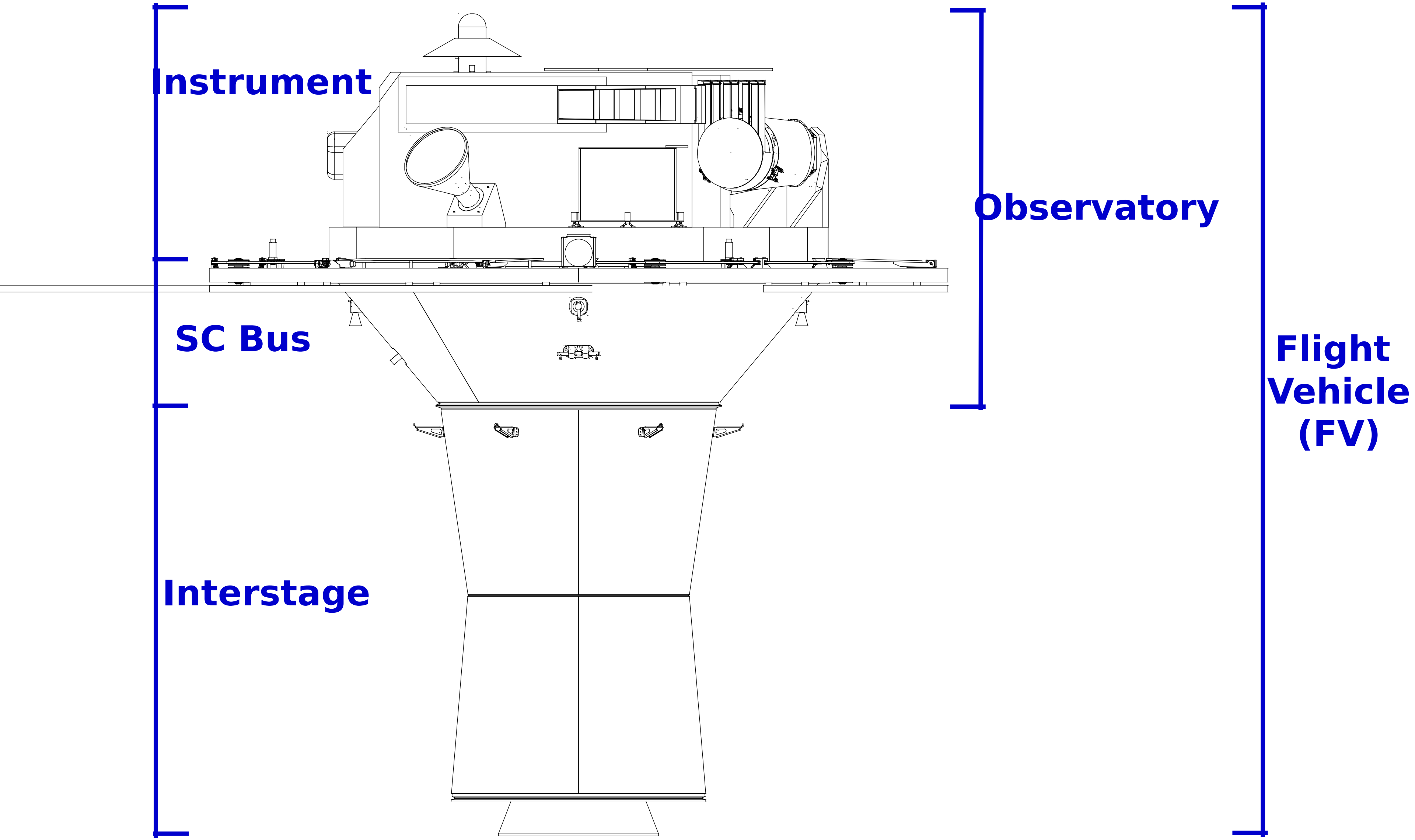
Trades

- Active vs Passive Control Of Spin Rate & Precession Rate
- Thrusters vs Electromagnetic Torquers for Solar Precession Back-Up, Augmentation, & Acquisition
- Swept vs Non-Swept Solar Array/Sun Shield
- Trim Tab Configuration & Sizing
- Center of Mass Control vs Center Of Pressure Control
- Center of Pressure Control Configuration Options & Sizing
- Trim Mass Configuration
- Sun Shield Geometry Configurations
- Elastomeric vs Metal Diaphragm
- Material Selection On Sun Shield
- Thruster Configuration, Sizing, & Layout
- Star Tracker Selection

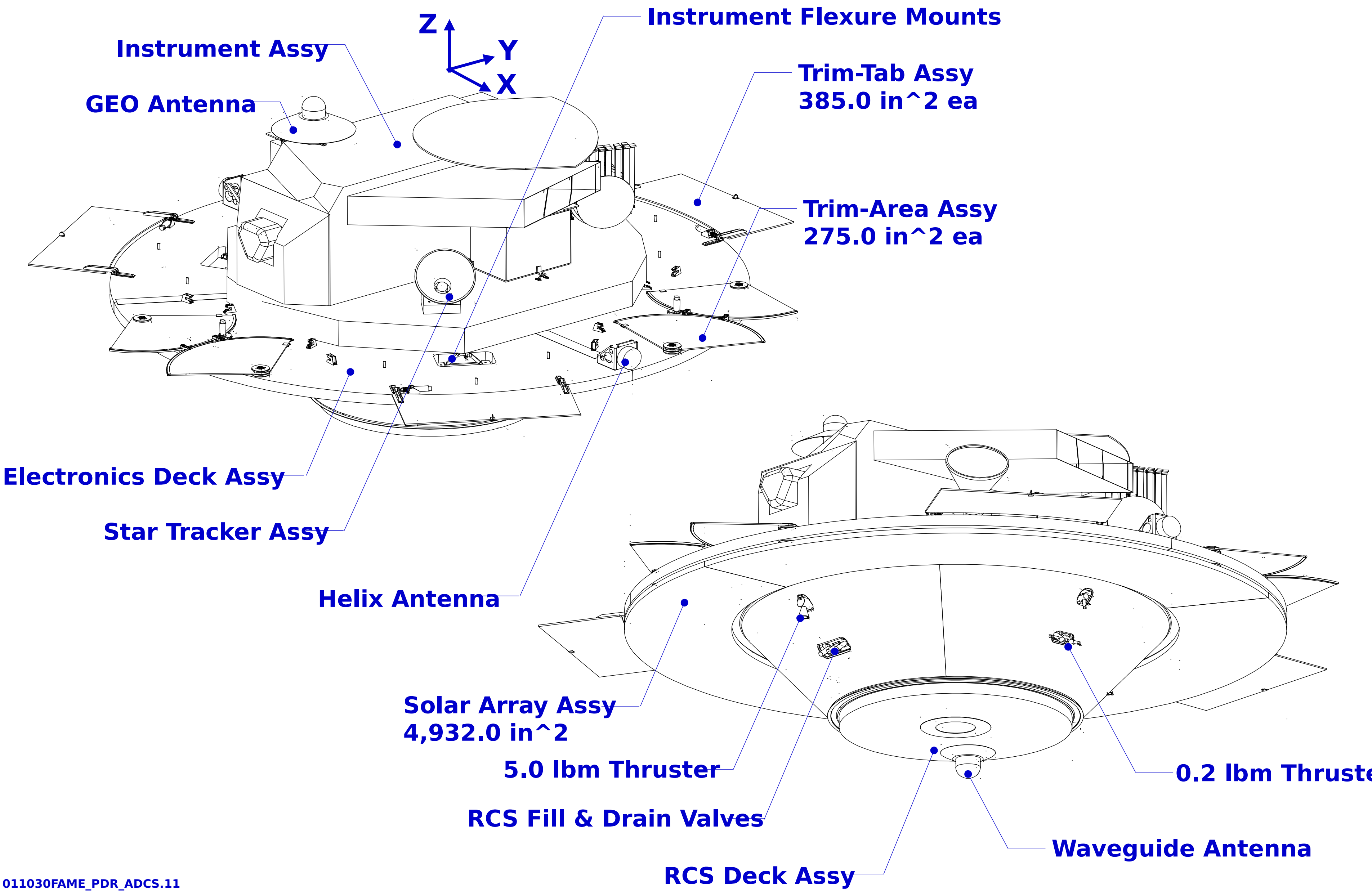
ADCS H/W Block Diagram & Interfaces



FAME Views (1 of 2)

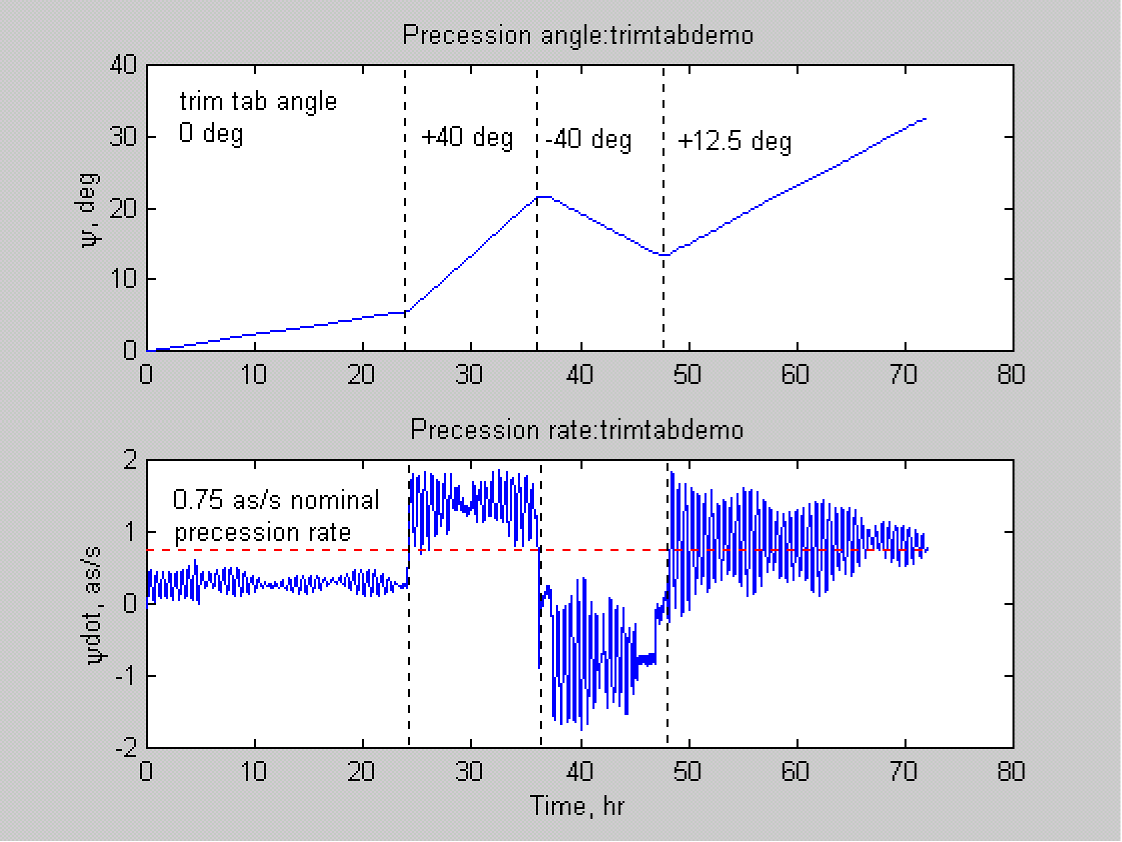


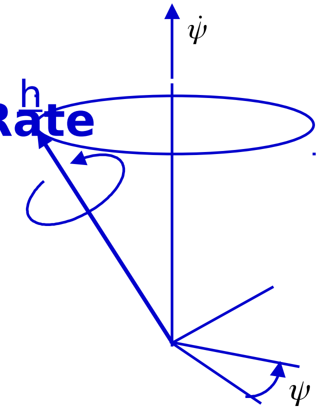
FAME Views (2 of 2)

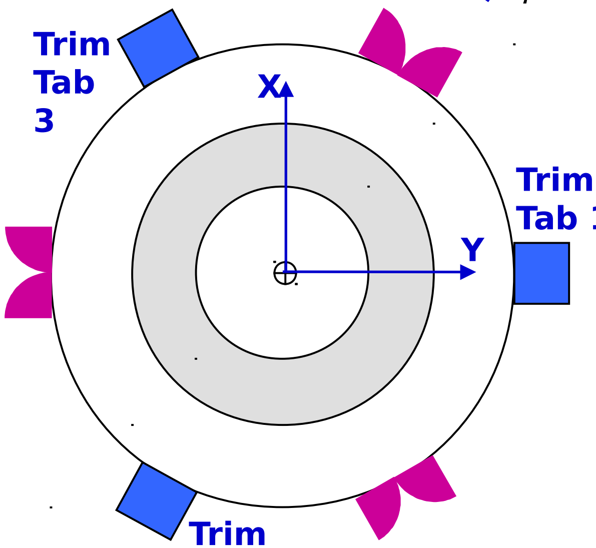


Precession Rate Control Using Trim Tabs

- **Simulation Includes:**
  - **Orbit Dynamics and Spin Attitude Dynamics**
  - **Ideal Solar Radiation Model, Gravity, Magnetic Torque Disturbances**
  - **Torque Rod Nutation Damping**
  - **Effect of Trim Tab Deflection Angle on Precession Rate**

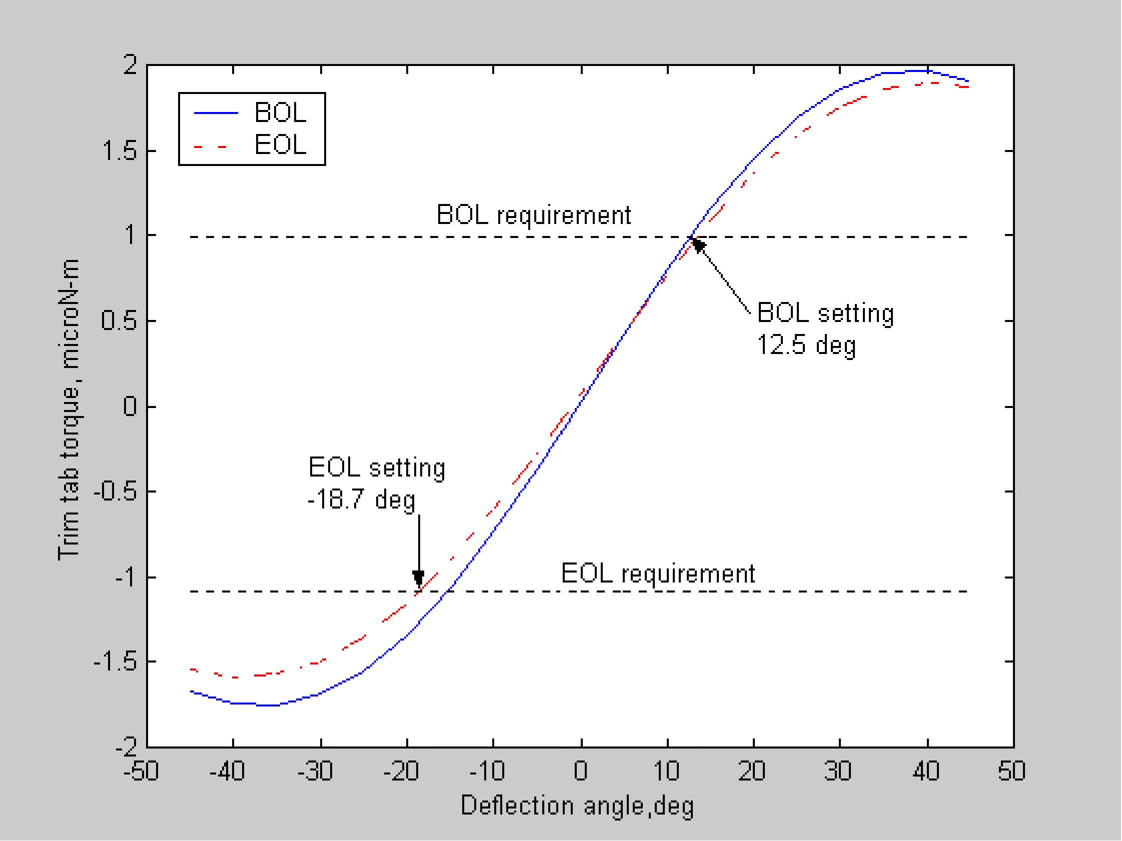






Trim Tab Adjustment Interval for Balance Maintenance

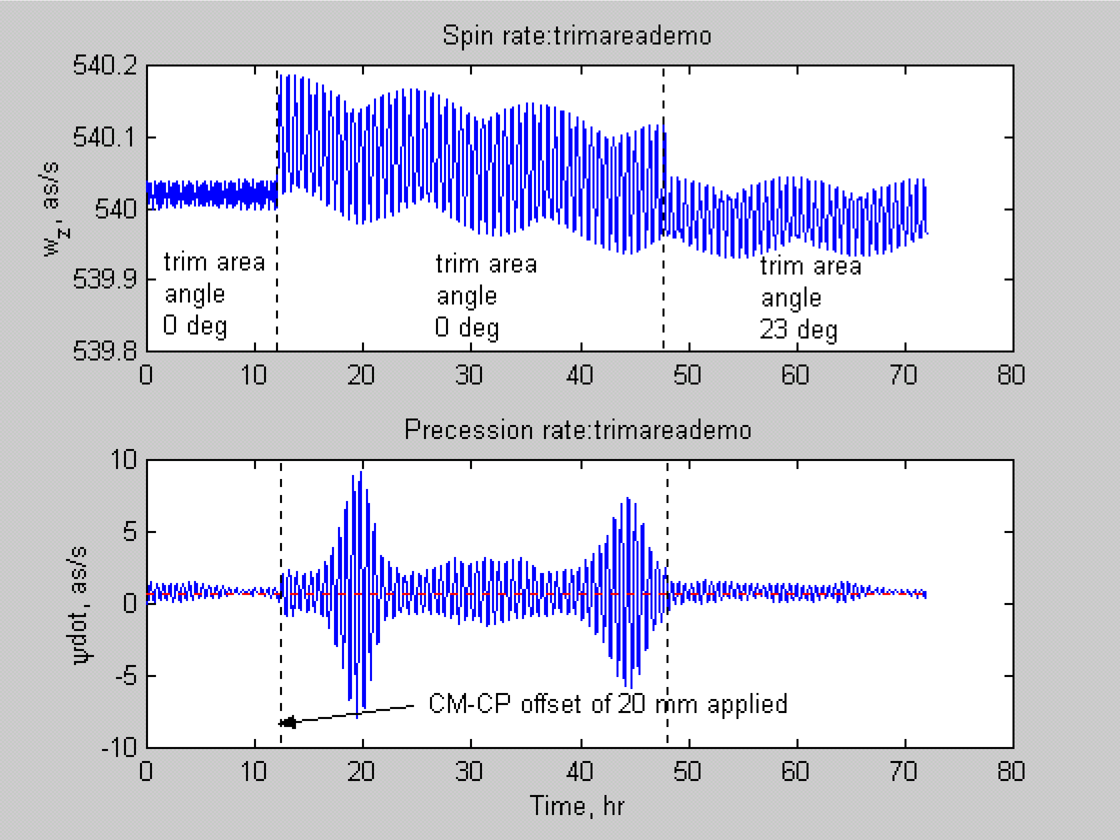
- Station Keeping to Accommodate Optical and Mass Property Changes for the 5-Year Mission
- Precession Torque Variation Due to Precession Period Change of +/- 2days (T_u, 10-6 N-m):
  - +/- 0.13
- Trim Tab Torque Requirement (T_u-6 N-m):
  - 0.99 (BOL) to -1.08 (EOL)
- Trim Tab Adjustment:
  - Initial Setting at 20 Day Period
  - Adjust the Tabs When the Precession Period Exceeds +/- 2 Days
  - Adjustment Interval: About 16 Times During the 5 Year Mission Period or Every 3-4 Months

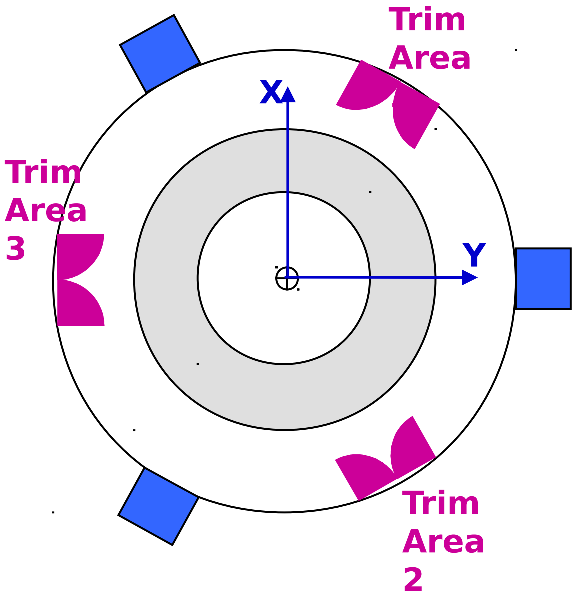


- Since the Trim Tab Adjustment Will Disturb Mass Property, It Is Recommended That Other Balancing Process Including Trim Masses and Trim Areas Be Conducted at the Same Time

CM-CP Offset Control Using Trim Areas

- **Simulation Includes:**
  - **Orbit Dynamics and Spin Attitude Dynamics**
  - **Ideal Solar Radiation Model, Gravity, Magnetic Torque Disturbances**
  - **Torque Rod Nutation Damping, Effect of CM-CP Offset (20 mm Along Y Axis)**
  - **CM-CP Offset Correction Using Trim Areas (Rotate Trim Area 1 and 2)**
- **Trim Tab CP Shift Required Capability 20 mm; Designed Capability 60 mm**





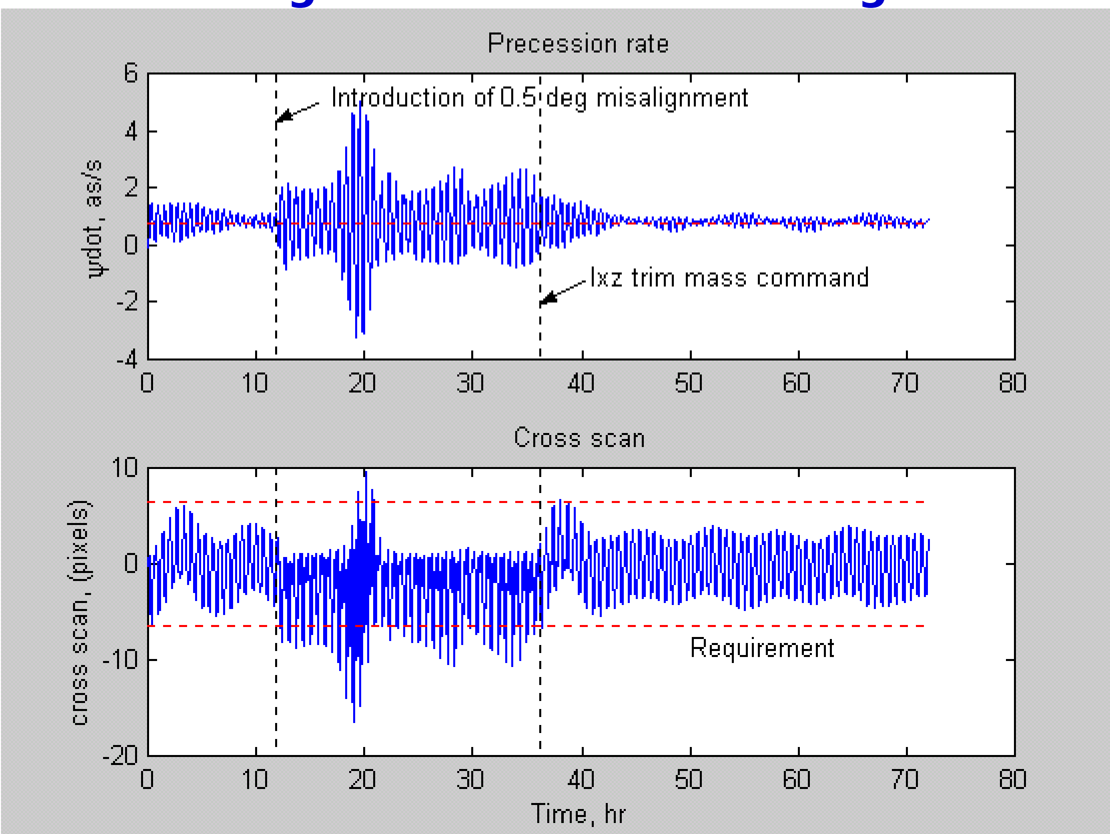
Trim Tabs:

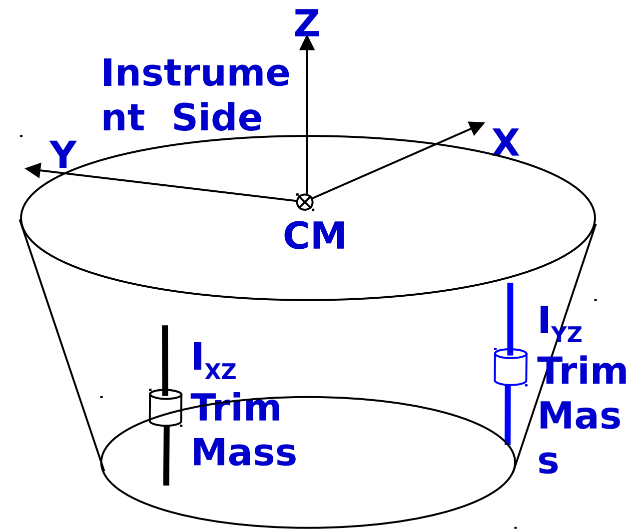
3 Sets Total, 120 Deg Separation

Al Kapton Coating

Principal Axis Misalignment Control Using Trim Masses

- **Simulation Includes:**
  - **Orbit Dynamics and Spin Attitude Dynamics**
  - **Ideal Solar Radiation Model, Gravity, Magnetic Torque Disturbances**
  - **Torque Rod Nutation Damping**
  - **Effect of Spin Axis Misalignment (0.5 Deg in XZ Plane)**
  - **Misalignment Correction Using Ixz Trim Mass by 58 mm (2.28 in)**





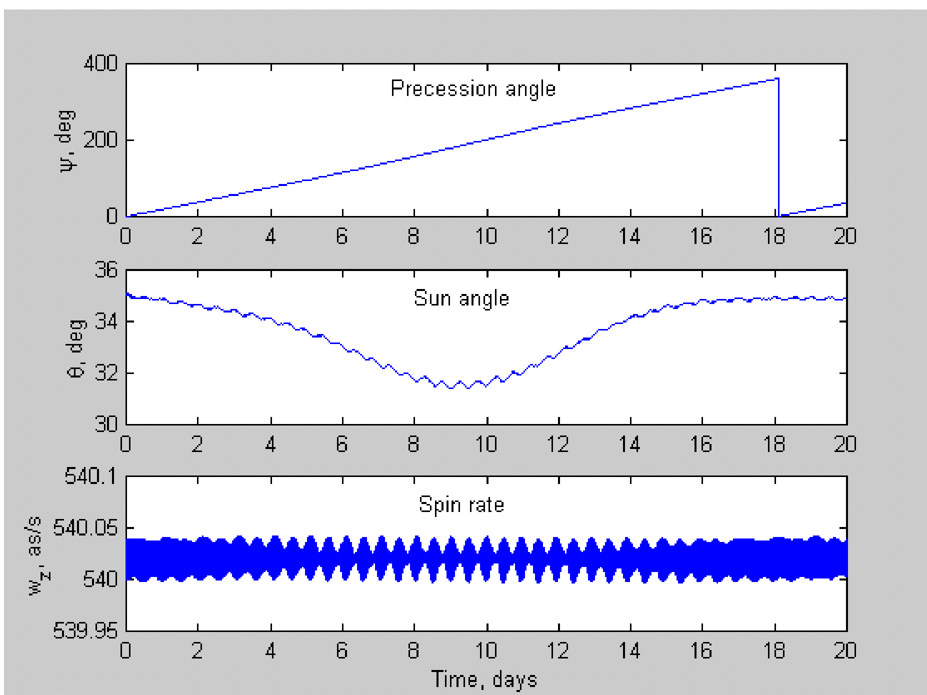
Trim Mass Sizing

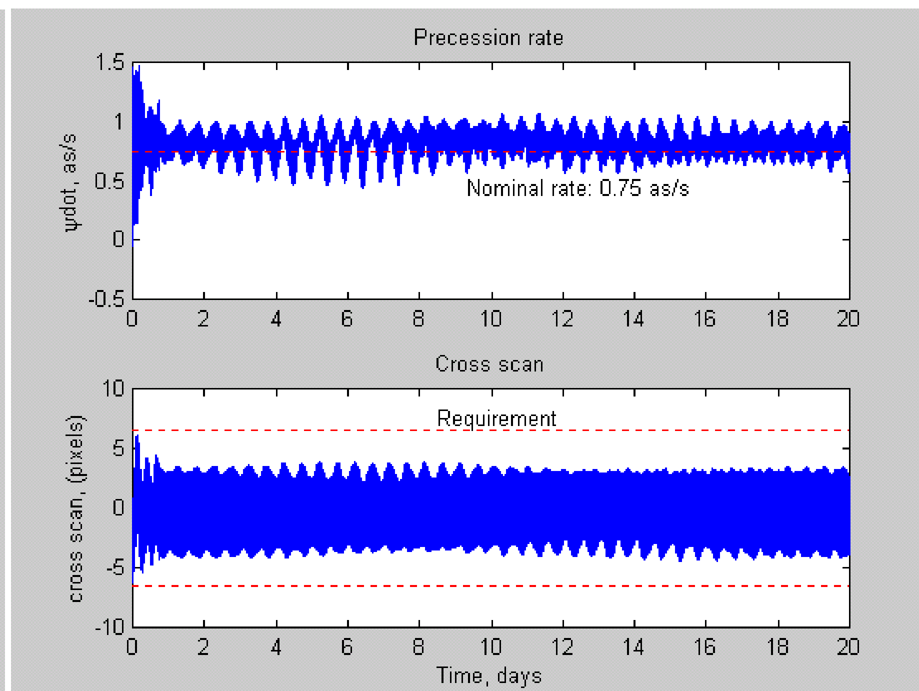
Trim mass ID	Mass (kg)	Stroke (m)	Null trim mass position from CM ([X,Y,Z], m)	Capability ($kg\text{-}m^2$)	Remarks
I_{XZ}	3	+/- 0.23	[-0.48, 0, -0.38]	$\Delta I_{XZ} = 0.33$	Spin axis misalignment correction
I_{YZ}	3	+/- 0.23	[0, -0.48, -0.38]	$\Delta I_{YZ} = 0.33$	

Error Sources	ΔI_{XZ}, ΔI_{YZ} (kg-m2)	Rationale/Remarks
Spin Balance Residual	0.045	Capability of NRL spin balance machine
Trim Areas	0.042	Two fully inboard, one fully extended
Trim Tabs	0.000	Symmetric placement & deployment angles
Propellant Tank Offset	0.030	Half full tank after dry spin balance
Propellant Tank Tilt	0.072	Half full tank after dry spin balance
Propellant CM To Tank CL Offset	0.140	Half full tank, unsymmetric deployment of tank diaphragm
Instrument Doors	0.227	Spin balanced with doors closed
Totals		
Sum	0.556	Worst case error
RSS	0.284	
Sum	0.329	Total worst case error, assumes instrument doors open during spin balance
RSS (PDR Baseline)	0.172	Assumes instrument doors open during spin balance
Trim Mass Capability	0.330	
Baseline Margin	0.158	91% margin

Passive Solar Precession Simulation

- **Simulation Includes:**
  - **Orbit Dynamics and Spin Attitude Dynamics**
  - **Ideal Solar Radiation Mode, Gravity, Magnetic Torque Disturbances**
  - **Torque Rod Nutation Damping**
  - **Trim Tab Deflected at 12.5 Deg for Precession Control**
- **Performance Summary:**
  - **18.1 Day Average Precession Period (Requirement: 20 +/- 2 Days)**
  - **Sun Angle Between 35 and 31 Degrees (Requirement: 35 +/- 5 Deg)**
  - **0.2 μrad/sec (0.04 as/s) Spin Rate Variation (Requirement: +/- 0.262 μ rad/sec)**
  - **Cross Scan Variation Between 3.75 and - 4.44 Pixels (Requirement: +/- 6.5 Pixels)**





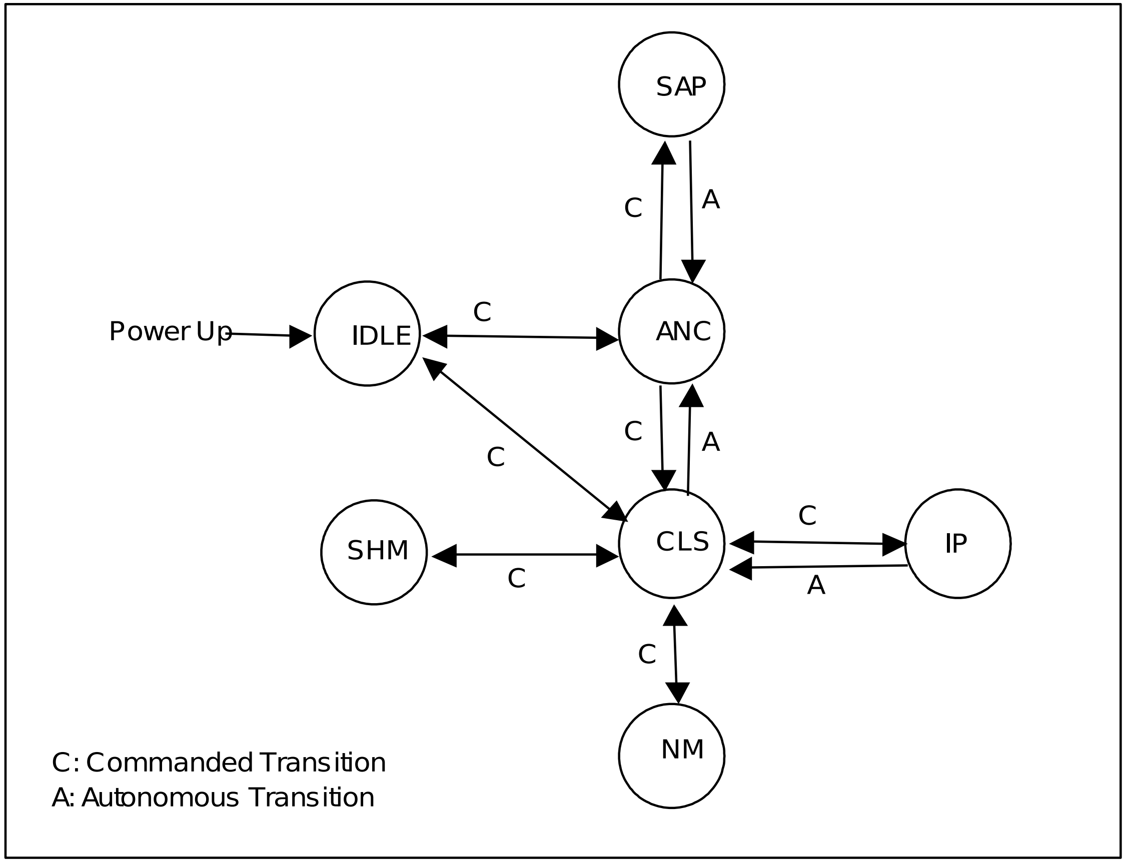
ADCS Mode Implementation (1 of 2)

- **Derived Control Modes**

Mode	Objective	Measurement Capabilty	ADCS Hardware
Idle	Processor Reboot	None	None
Safe Hold	Points -Z Body Axis To Sun +/- 20Deg	Coarse Sun Vector	Coarse Sun Sensor (CSS), Thrusters
Closed Loop Spin	Closed Loop Spin Rate Changes	Body Rates	IMU, SSS, Thrusters [SSS Not Needed For Control]
Active Nutation Control	Control Nutation At High Spin Rates	Body Rates	Inertial Measurement Unit (IMU), Spinning Sun Sensor (SSS), Thrusters [SSS Not Needed For Control]
Spin Axis Precession	Closed Loop Precession Of Spin Axis	Sun Vector & Body Rates	IMU, SSS, Thrusters
Inertial Pointing	Hold Any Inertially Defined Attitude	Attitude & Body Rates	Star Tracker (ST), IMU, Thrusters
Normal	Spin Rate, Sun Angle, Precession Rate & Nutation Angle Control	Sun Angle, Spin Rate, Precession Rate & Nutation Angle	ST, IMU, TAM, Electromagnetic Torquers (EMTs) [TAM For Control Only]

ADCS Mode Implementation (2 of 2)

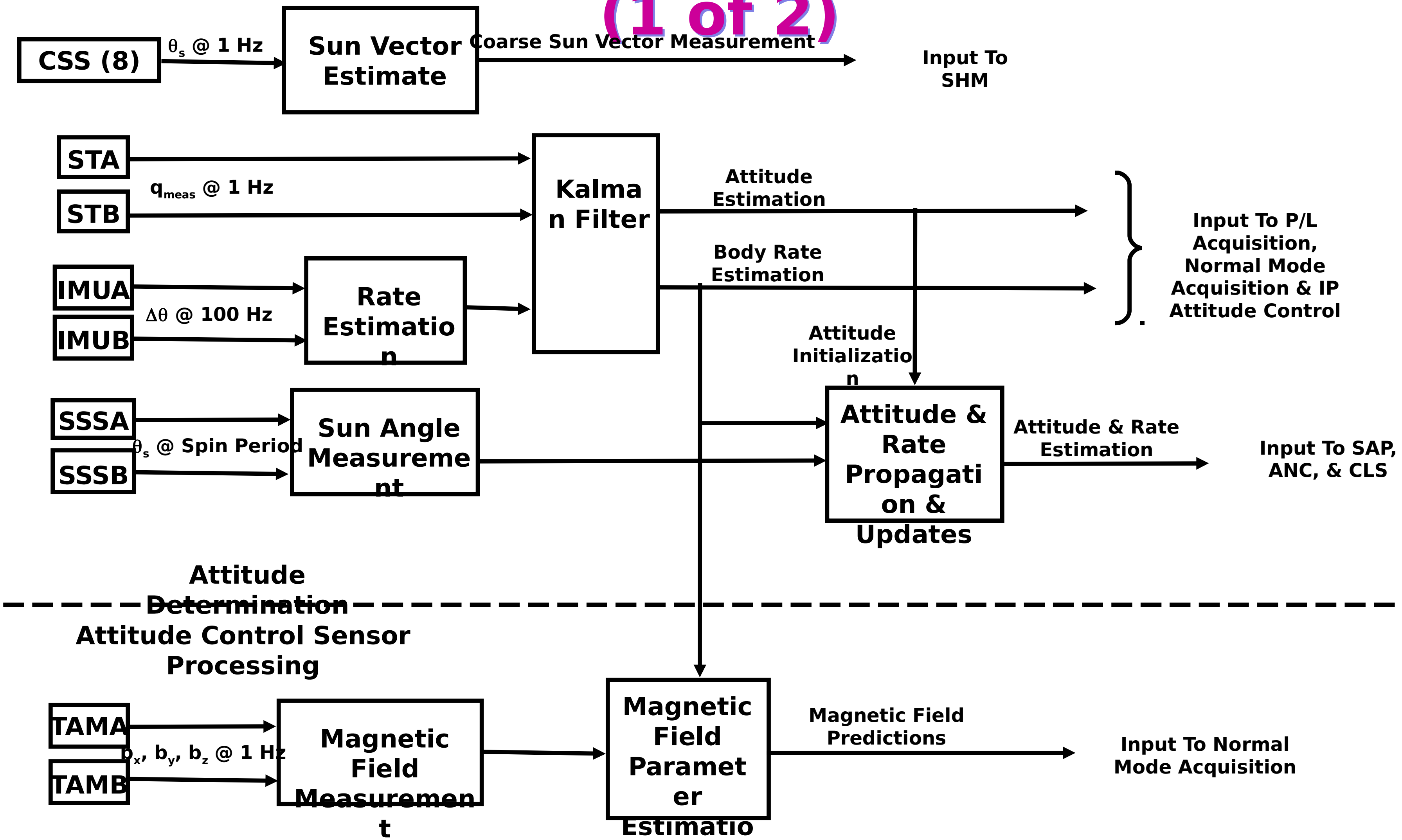
- Science Acquisition
- CLS Low Rate; Trim Mechanism to Nominal Positions
- IP to Science Sun Angle, Spin Rate, Precession Rate
- CLS
- NM
- Adjust Trim Tabs (Precession Adjustment)
- Adjust Trim Masses (Dynamic Balance)
- Adjust Trim Areas (CP-to-CM Balance)
- Alignment Calibration With Instrument
- Fine Adjustment of Trim Mechanisms
- Science Acquisition
- Science Data Collection



- AKM Operations
- ANC
- CLS to Low Rate for Attitude Update
- IP Slew To AKM Burn Attitude
- CLS To 10 (TBR) RPM
- ANC
- SAP
- ANC
- CLS To 60 (TBR) RPM
- ANC
- SAP If Required
- ANC
- AKM Burn
- ANC
- CLS to Low RPM
- ANC

- Initial Acquisition
- Launch In Idle
- CLS To Remove Tip Off Rates
- SHM To Slew To Sun
- CLS To Low RPM
- ANC

Sensor Processing Implementation (1 of 2)



Note: Data Checking & Error Detection Done On All Sensor Data

Sensor Processing Implementation (2 of 2)

- Safe Hold Mode
  - CSS Only
    - Algorithm & Design Heritage: Non-NRL Program
- Closed Loop Spin Rate Control, Active Nutation Control, & Spin Axis Precession Modes
  - IMU With SSS Roll Updates
    - Algorithm & Design Heritage: Clementine, NRL Bus
- Inertial Pointing & Normal Mode
  - IMU/ST Kalman Filter Solution
    - Algorithm & Design Heritage: Clementine, ICM, & NEMO
  - Instrument/ST Kalman Filter Solution for Normal Mode Only
    - Will Use Measured Body Rates From Instrument or Estimated Body Rates to Replace IMU Inputs to Kalman Filter
    - New Algorithms But Not Difficult Development

Attitude Control Implementation

- **Safe Hold Mode**
  - **Re-Orient Vehicle to Point -Z Body Axis to Sun Within TBR Deg**
  - **Algorithm & Design Heritage: Non-NRL Program**
- **Spinning Modes**
  - **Closed Loop Spin Rate Control, Active Nutation Control & Spin Axis Precession Modes**
    - **Algorithm & Design Heritage: Clementine, NRL Bus, ICM**
- **Inertial Pointing**
  - **Holds Commanded Attitude to Support ΔV & Non-ΔV Activities**
  - **Algorithm & Design Heritage: Clementine, ICM, & NEMO**
- **Normal Mode**
  - **Deadband Control of Spin Rate, Precession Rate, Sun Angle & Nutation Angle Using Electromagnetic Torquers**
  - **New Control Algorithm Design for FAME**
  - **Magnetic Field Variation Measurement**
    - **Algorithm for Detection of Small Spin Period Oscillation On Top of Larger Bias Signal New for FAME**

Star Tracker

- **Procurement Status**
  - RFP Released: June 2001
  - Proposals Received: August 2001
  - Final Selection Held Up Pending Funding
  - Award Target Date: Dec 2001
  - Required Delivery Date: June 2003
- **Key Performance Requirements**
  - Quaternion Output
  - Pitch and Yaw Pointing Accuracy of 5 Arcseconds (1 Sigma)
  - Roll Pointing Accuracy of 15 Arcseconds (1 Sigma)
    - Performance Characteristics Need to Be Maintained Over A 20ºC Temperature Range to Support Instrument Acquisition
  - Maximum Spacecraft Slew Rate for Performance Is 0.3 Degrees/Second (Slew Rate During Instrument Acquisition Is 0.15 Degrees/Second)
  - Data Output Rate of 1 Hz

Inertial Measurement Unit

- Procurement Status
  - RFP Released: June 2001
  - Proposals Received: August 2001
  - Final Selection Held Up Pending Funding
  - Award Target Date: Dec 2001
  - Required Delivery Date: December 2002
- Key Performance Requirements
  - Bias Stability of 1 Degrees/Hour
  - Angular Random Walk of 1 Degree/Root-Hour
  - Scale Factor Stability of 100 ppm
  - Scale Factor Linearity of 100 ppm

Electromagnetic Torquers

- **Procurement Status**
  - **RFP Planned Release Date: Feb 2002**
  - **Award Target Date: June 2002**
  - **Required Delivery Date: June 2003**

- **Characteristics of Candidate Unit (BF Goodrich/ Ithaco TR30CFR)**
  - **Mass: 0.95 KG**
  - **Size: 2.3 dia x 50 cm**
  - **Power (Standby): 0 W**
  - **Power (Operating): 5.8 W**
  - **Linear Moment Output (saturated): 40 Amp-m^2**
  - **Scale Factor: 0.20 Amp- m^2/milli-Amp**
  - **Coil Resistance: 132 Ohms**
  - **Linear Voltage: 24 V**
  - **Saturation Voltage: 28 V**

Three-Axis Magnetometer

- **Procurement Status**
  - **RFP Planned Release Date: Feb 2002**
  - **Award Target Date: June 2002**
  - **Required Delivery Date: June 2003**
- **Characteristics of Candidate Unit (BF Goodrich/ Ithaco IM-103)**
  - **Mass: 0.23 kg**
  - **Size: 15.5 x 4.2 x 3.8 cm**
  - **Power (Standby): 0.95 W**
  - **Power (Orbit Average): 0.95 W**
  - **Power (Operating): 0.95 W**
  - **Magnetic Field Range: ± 600 mG in three axes**
  - **Measurement Accuracy: 4 mG (3σ)**
  - **Scale Factor: 8.3333 V/G**
  - **Signal Outputs: Three Voltages Proportional to B field (0 to ± 5V), Voltage Proportional to Temperature (0 to 5V)**
  - **Power Input: + 15V (± 5%)**
    - 15V (± 5%)

Spinning Sun Sensor

- Located Two Sets of Adcole Spinning Sun Angle Sensors That Were Flight Spares for Another NRL Project
  - Retest Required For Each
- Characteristics
  - System Consists of Sensor Head and Electronics Box
  - 180° x 0.5° FOV, Requires Use on Spinning Spacecraft
  - LSB 0.5°, 0.25° Transition Accuracy
  - Mass: 0.51 kg (Electronics), 0.15 kg (Sensor Head)
  - Sensor Size: 5.1 x 6.5 x 3.4 cm
  - Electronics Size: 8.9 x 7.6 x 8.3 cm
  - Power Input (Electronics): 27 ± 1 Vdc (on NRL Bus This Was Operated Over a Range From 24 to 32 Vdc)
  - Signal Output (Electronics): 9-bit Parallel Gray Code,
    - Sun “Pulse”: Digital “1” (Sun Presence)
    - Digital “0” (Sun Absence)

Coarse Sun Sensor

- **Procurement Status**
  - **RFP Planned Release Date: Feb 2002**
  - **Award Target Date: June 2002**
  - **Required Delivery Date: June 2003**
- **Characteristics**
  - **Mass: 0.011 kg**
  - **Power: n/a**
  - **Measurement: Cosine Of Angle Between Cell Normal & Sun**
  - **Operational FOV: 80 Deg Half Angle Cone**
  - **Sun Presence FOV: 90 Deg Half Angle Cone**
  - **Interface: Analog Output, Two Wire Interface**

Propellant Budget

	Configuration	Mprop (kg)	Mprop (lbm)
1	Flight Vehicle, Wet AKM	8.9	19.7
2	Flight Vehicle, Dry AKM	7.0	15.3
3	Observatory (Post-AKM Jettison)	2.2	4.8
	Total	18.1	39.9

1	Flight Vehicle, Wet AKM		
	Null tip-off from Delta 3rd stage	0.10	
	Inertial pointing (3-axis limit cycle)	0.14	
	Slew maneuvers	0.40	
	SHM spin-up/down	0.06	
	Inertial ptg during ACS Delta-V	0.06	
	AKM spin-up	1.36	
	Active Nutation Control	6.52	
	Spin axis precession	0.27	
	subtotal	8.9	kg

2	Flight Vehicle, Dry AKM		
	ANC following AKM firing	1.84	
	Post-AKM spin-down	1.11	
	Slew maneuvers	0.58	
	Inertial ptg during ACS Delta-V	0.07	
	Inertial pointing (3-axis limit cycle)	3.37	
	subtotal	7.0	kg

3	Spacecraft (post-Interstage separation)		
	Slew maneuvers	0.27	
	Inertial pointing (3-axis limit cycle)	1.07	
	Inertial ptg during ACS Delta-V	0.15	
	SHM spin-up/down	0.71	
	subtotal	2.2	kg

Mass Budget

Hardware		# Flt Units	Mass /Unit (kg)	Total Mass (kg)	Comments
Star Tracker	ST	2	3.0	6.0	Unit Redundancy
Inertial Measurement Unit	IMU	2	0.75	1.5	Unit Redundancy (Need To Add Shielding)
Electromagnetic Torquer	EMT	3	1.0	3.0	Internal Redundancy
Spinning Sun Sensor (X Adcole)	SSS	2	0.7	1.4	Unit Redundancy
Coarse Sun Sensors	CSS	10	0.01	0.1	High Reliability
Magnetometer	TAM	2	1.0	2.0	Unit Redundancy
Totals				14 kg	

Power Budget By Mode

Mode	Idle	Safe Hold	Active Nutation Control	Closed Loop Spin	Spin Axis Precession	Inertial Pointing	Normal
ST	0	0	0	0	0	30	30
IMU	0	0	24	24	24	24	24
EMT	0	0	0	0	0	0	11.6
SSS	0	0	0.6	0.6	0.6	0.6	0.6
CSS	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TAM	0	0	0	0	0	0	2.0
Max Totals(1) Min Totals(2)	0 W 0 W	0.0 W 0.0 W	24.6 W 24.6 W	24.6 W 24.6 W	24.6 W 24.6 W	54.6 W 27.6 W	68.2 W 40.9 W

(1) Using Hot Redundancy X In Some Cases
(2) Using Minimal Redundancy

ADCS Test & Verification Plan

- Algorithm Design & Software Implementation Elements
  - Analysis & Simulation Testing By Designer
  - Peer Reviews
  - Subsystem Level Performance Verification Via Simulation
  - System Level Functional Verification Via Flight Software Test Bed Simulation

- Hardware Elements
  - Vendor Full Performance Testing
  - Vendor Environmental Testing
  - Subsystem Limited Performance Testing
  - Subsystem Functional Testing
  - System Level Functional Testing
  - System Level Environmental Testing

Milestones

Task	Start Date	Finish Date
PDR	10/30/01	10/31/01
Star Tracker Contracting	4/15/01	12/15/01
Star Tracker Procurement	12/15/01	6/15/03
Inertial Measurement Unit Contracting	4/15/01	12/15/01
Inertial Measurement Unit Procurement	12/15/01	12/15/02
CDR	8/12/02	8/13/02
Spinning Sun Sensor Contracting	1/1/02	6/1/02
Spinning Sun Sensor Re-ATP	12/1/02	5/3/03
Electromagnetic Torquer Contracting	1/1/02	6/1/02
Electromagnetic Torquer Procurement	6/1/02	6/1/03
Three Axis Magnetometer Contracting	1/1/02	6/1/02
Three Axis Magnetometer Procurement	6/1/02	6/1/03
Coarse Sun Sensor Contracting	1/1/02	6/1/02
Coarse Sun Sensor Procurement	6/1/02	6/1/03
Integration Of ACS Flight Sensors	8/11/03	8/29/03?
Observatory Integration and Test	12/26/03	5/21/04

Requirement Summary Status (1 of 2)

Spacecraft Requirements Document	Paragraph	Meet	Basis
Attitude Determination & Control Subsystem	3.21.1	Yes	PDR Design
Spin Period	3.21.1.1	Yes	PDR Design & Simulation
Modelable Spin Rate Variation	3.21.1.2	Yes	PDR Design & Simulation
Sun Angle	3.21.1.3	Yes	PDR Design & Simulation
Precession Period	3.21.1.4	Yes	PDR Design & Simulation
Modelable Cross Scan Motion	3.21.1.5	Yes	PDR Design & Simulation
Principal Axis Misalignment	3.21.1.6	Yes	PDR Design & Simulation
Instrument Attitude Acquisition	3.21.1.7	Yes	PDR Design & Simulation
Observatory Balance & Trim	3.21.1.8	Yes	PDR Design & Simulation
CP to CM Offset Trim	3.21.1.8.1	Yes	PDR Design & Simulation
Principal Axis Misalignment	3.21.1.8.2	Yes	PDR Design & Simulation
Solar Precession Rate Adjustment	3.21.1.8.3	Yes	PDR Design & Simulation
Operational Modes	3.21.1.9	Yes	PDR Design & Simulation
Closed Loop Spin Rate Control	3.21.1.9.1	Yes	PDR Design & Simulation
Active Nutation Control	3.21.1.9.2	Yes	PDR Design & Simulation
Spin Axis Precession	3.21.1.9.3	Yes	PDR Design & Simulation
Inertial Pointing	3.21.1.9.4	Yes	PDR Design & Simulation

Requirement Summary Status (2 of 2)

Spacecraft Requirements Document	Paragraph	Meet	Basis
Data Collection Mode	3.2.1.1.9.5	Yes	PDR Design & Simulation
Safe Mode	3.2.1.1.9.6	Yes	PDR Design & Simulation
Sensor Processing	3.2.1.1.10	Yes	PDR Design
Attitude Solution	3.2.1.1.10.1	Yes	PDR Design, Heritage & Simulation
Rate Measurement	3.2.1.1.10.2	Yes	PDR Design, Heritage & Simulation
Magnetometer Data Processing	3.2.1.1.10.3	Yes	PDR Design & Simulation
Sensors	3.2.1.1.11	N/A	
Star Tracker	3.2.1.1.11.1	Yes	PDR Design, Heritage & Sensor Spec
Inertial Measurement Unit	3.2.1.1.11.2	Yes	PDR Design, Heritage & Sensor Spec
Spinning Sun Sensor	3.2.1.1.11.3	Yes	PDR Design, Heritage & Sensor Spec
Coarse Sun Sensor	3.2.1.1.11.4	Yes	PDR Design & Sensor Spec
Three Axis Magnetometer	3.2.1.1.11.5	Yes	PDR Design, Heritage & Sensor Spec
Control	3.2.1.1.12	Yes	PDR Design
High Spin Rate Modes	3.2.1.1.12.1	Yes	PDR Design & Simulation
Low Spin Rate or Inertial Modes	3.2.1.1.12.2	Yes	PDR Design & Simulation
Actuators	3.2.1.1.13	N/A	
Thrusters	3.2.1.1.13.1	Yes	PDR Design, Heritage, Simulation & Sensor Spec
Electromagnetic Torquers	3.2.1.1.13.2	Yes	PDR Design, Simulation & Sensor Spec

Open Issues

- Instrument Attitude Acquisition Error Budget
- Star Tracker Selection
- Elimination of Star Tracker Covers
- Availability of ICM IMUs
- Antenna Size & Impact On Spin Rate Variation
- Propellant Margin On Small Launch Vehicle
- Instrument Thermal Radiation Produced Disturbance Torque

Backup

Peer Review Participants

Held 12 October 2001

- **Martin Houghton GSFC**
- **Wayne Dellinger APL**
- **Robin Vaughan APL**
- **Marv Levenson NRL Contractor (Retired NRL ACS Section Head)**
- **Sam Hollander NRL Contractor (Retired NRL Controls Branch Head)**
- **Russ Barnes BEI(NRL)**
- **Joe Hauser NRL Design Test & Processing Branch Head**
- **George Flach NRL Space Elec Systems Dev Branch Head**
- **Michael Mook NRL ACS Section Member**
- **Al Bosse NRL Controls Branch Head**
- **Various FAME Subsystem Leads**

Derived Requirements

Observing Parameters Requirements Flow-Down

- Spin Period of 40 +/- 4 Min
  - Slow S/C Rotation Capability
    - See Science Collection Requirements Flow-Down For Further Constraints Which Lead to Derived Requirements
- Precession Period of 20 +/- 2 Days About Sun
  - Slow S/C Maneuver Through Defined Pattern
    - See Science Collection Requirements Flow-Down for Further Constraints Which Lead to Derived Requirements
- Sun Angle of 35 +/- 5 Deg
  - Coarse Pointing Control
    - See Science Collection Requirements Flow-Down for Further Constraints Which Lead to Derived Requirements

Science Collection Requirements Flow-Down (1 of 2)

- Top Level Science Collections Requirements
  - All Motions Modelable
    - Only Passive Control Allowed
    - Active Control Duty Cycle < 10% [TBR] (1 Cycle 24 Hrs [TBR])
    - Resume Science Collections Within 3 Hours After Leaving Eclipse
  - Spin Rate Variation < +/- 0.262 μrad/sec Over 5 Min
  - Along Scan Jitter Requirements
  - Maximum Cross Scan Motion Per CCD Crossing < 9.5 Pixels
    - Includes Instrument CCD Misalignment & Principal Axis Misalignment
  - Cross Scan Jitter Requirements
- Derived Requirements From Science Collection
  - Mass Properties Derived Requirements (DR 1 of 14)
  - Sun Shield Design Derived Requirements (DR 2 of 14)
  - Optical Properties Derived Requirements (DR 6 of 14)
  - Trim Mass System Derived Requirements (DR 3 of 14)
  - Trim Tab System Derived Requirements (DR 4 of 14)
  - Trim Area System Derived Requirements (DR 5 of 14)

Science Collection Requirements Flow-Down (2 of 2)

- **Derived Requirements From Science Collection (Cont)**
  - **Thruster Sizing, Configuration, Placement Derived Requirements (DR 7 of 14)**
  - **EMT Derived Requirements (EMT H/W Chart)**
  - **IMU, ST, KF Sensor Processing Derived Requirements (DR 11 of 14)**
  - **SSS Sensor Processing Derived Requirements (DR 11 of 14)**
  - **Closed Loop Spin Rate Control Mode Requirement (AC & Mode Charts)**
  - **Inertial Pointing Mode, Normal Mode Capability Derived Requirements (AC & Mode Charts)**
  - **FPA Spin Axis to S/C Principal Axis Misalignment < 150 μrad (DR 1 of 14)**
  - **CCD to FPA Misalignment < 2 Pixels (Instrument Requirement)**
  - **Instrument to S/C Axes On-Orbit Alignment Calibration Derived Requirements (DR 9 of 14)**
  - **Ground Alignment Knowledge Derived Requirements (DR 8 of 14)**
  - **Mechanical Design Jitter Derived Requirements**

Instrument Acquisition Requirements Flow-Down (1 of 2)

- **Initial On-Orbit Instrument Attitude Acquisition**
  - **Implementation & Instrument Derived Requirements**
    - **0.11 Deg x 0.11 Deg Maximum Search Area**
    - **600 x 600 Pixel Window Search Capability**
    - **Instrument & Flight Software to Store, Target & Process Acquisition Stars**
    - **Alignment Knowledge Between Instrument & S/C Axes Must Be Known to Within 80 μradians Prior to Launch (DR 8 Of 14)**
    - **Alignment Shifts Between Instrument & S/C Axes Must Be Within 1200 μradians From Ground Calibration to On-Orbit Checkout (DR 8 of 14)**
  - **Spacecraft Requirements**
    - **Stability of Spacecraft Axes (DR 8 Of 14)**
    - **S/C Attitude Knowledge to Within 640 μradians Per Axis (DR 8 Of 14)**
    - **IMU, ST, KF Sensor Processing Derived Requirements (DR 11 Of 14)**

Instrument Acquisition Requirements Flow-Down (2 of 2)

- Instrument Attitude Re-Acquisition Within 1 [TBR] Minute
  - Implementation & Instrument Derived Requirements
    - 600 x 600 Pixel Window (Time to Search Not Allowed)
    - Flight Software to Store, Target & Process Acquisition Stars
    - Alignment Knowledge Between Instrument & S/C Axes Must Be Known to Within 25 [TBR] μradians
      - On-Orbit Alignment Update Derived Requirement (DR 9 of 14)
    - Alignment Shifts Between Instrument & S/C Axes Must Be Within 115 [TBR] μradians From Last Alignment Update
      - Instrument Derived Requirements (DR 9 of 14)
  - Spacecraft Requirements
    - Stability of Spacecraft Axes (DR 9 of 14)
    - S/C Attitude Knowledge to Within 250 μradians Per Axis (DR 9 of 14)
    - IMU, ST, KF Sensor Processing Derived Requirements (DR 11 of 14)

Geosynchronous Orbit Requirements Flow-Down (1 of 2)

- Support Large Geosynchronous Orbit Insertion Burn
  - Pointing Control Error < 1 Deg Due to AKM Burn
    - AKM Thrust Vector Misalignment Derived Requirements (DR 10 of 14)
    - Mass Properties Derived Requirements (DR 1 of 14)
    - 60 [TBR] RPM Spin Rate Required to Minimize Pointing Error
  - Pointing Control Error < 1 Deg Prior to AKM Burn for Prolate Spinner
    - CLS, ANC, & SAP Mode Derived Requirements (AC & Mode Charts)
      - Thruster Sizing, Configuration, Placement Derived Requirements (DR 7 of 14)
      - IMU Derived Requirements (IMU H/W Charts)
      - Mass Properties Derived Requirement (DR 1 of 14)
      - Attitude Knowledge or Spin Axis Orientation Knowledge < 0.5 Deg
        - Attitude Initialization: IMU, ST, KF Sensor Processing Derived Requirements (DR 12 of 14)
        - Attitude Propagation: IMU Sensor Processing Derived Requirements (DR 12 of 14)
        - Roll & Sun Angle Updates: SSS Sensor Processing Derived Requirements (DR 12 of 14)

Geosynchronous Orbit Requirements Flow-Down (2 of 2)

Support Small Orbit Adjustment Burns

- Orbit Adjustment Burn Pointing Error < 1 Deg Prior to & During Burns
  - Hold Commanded Attitude to < 0.5 Deg
    - Inertial Pointing Mode Derived Requirements
      - Slew S/C From Any Attitude to Burn Attitude
      - Attitude Knowledge to < 0.5 Deg (DR 12 of 14)
      - IMU, ST, KF Sensor Processing Derived Requirement (DR 12 of 14)

Mission Duration Requirements Flow-Down

- Ensure High Probability of Success for 5 Year Mission
  - Provide Redundancy or High Reliability As Needed
    - Implementation
      - Cold Spares for ST, IMU, SSS, TAM
      - Internally Redundant EMTs
      - CSS Graceful Degradation
      - Thruster: Limited Back-Up
      - Trim Tabs: No Redundancy for Functionality
      - Trim Areas: Graceful Degradation With Loss of One of Three
      - Trim Masses: No Redundancy for Functionality
  - Provide Back-Up Attitude Control Mode to Safe S/C
    - Safe Hold Mode Derived Requirement (AC & Mode Charts)
  - Provide Back-Up Attitude Determination to Monitor Health
    - SSS & CSS Back-Up to ST/IMU/KF
      - SSS & CSS Derived Requirements (SP DR 12 of 14)

Derived Requirements (1 of 14) Mass Properties

Before Trim Mass Adjustment

Items	Requirements	Rationale
Izz (spin axis, centroidal MOI, kg-m^2)	240 +/- 10%	Major axis, gyroscopic stiffness, required solar precession torque range
Ixx	0.75 Izz ≤ Ixx ≤ 0.94 Izz	Itmax ≤ 0.95Is for spin stability Itmin ≥ 0.74Is to limit gravity gradient torque in transverse axes (Itmax-Itmin) ≤ 0.06Is to limit gravity gradient torque in spin axis
Iyy	0.75 Izz ≤ Iyy ≤ 0.94 Izz	
Ixx-Iyy	|Ixx-Iyy| ≤ 0.04 Izz	
Ixy	|Ixy| ≤ 0.02 Izz	
Ixz	|Ixz| ≤ 3.5e-4Izz	≤ 0.5 deg spin axis misalignment
Iyz	|Iyz| ≤ 3.5e-4Izz	
Xcm offset from the geometric axes	|Xcm| < 0.01 m	Control capability of trim areas for radial CM-CP offset control
Ycm offset from the geometric axes	|Ycm| < 0.01 m	
Zcm range from the solar array	0.17 m (BOL) – 0.21 m (EOL)	Trim tab control capability to accommodate axial CM-CP offset

After Trim Mass Adjustment

- **|Ixz| and |Iyz| Less Than 9.5e-6Izz to Meet 30 as Spin Axis Misalignment**

Derived Requirements (2 of 14)
Sun Shield Design (1 of 2)

Solar Array Panel Requirements

Items	Requirements			Rationale/Remarks
Quantity	Three (3)			To facilitate fabrication and assembly
Installation angle errors	Pitch angle error: ± 0.1 (TBR) deg Radial angle error: ± 0.1 (TBR) deg Clocking angle error: ± 0.1 (TBR) deg			Limited by solar precession, sun angle and spin rate variation requirements
Flatness	Less than 5 mm over 2 m length			Accommodate manufacturing and installation errors, thermal deformation
Surface area	1.095 ± 0.01 m^2 (per panel)			Provide smooth control torque for solar precession.
Optical properties (solar cells)		BOL	EOL	Sunside: Aluminized Kapton Shadeside: unspecified, EOL: 5 years at GEO Ca = solar absorptivity, ρ = Cs/(Cs+Cd) ε_h = hemispherical emissivity
	Ca	0.88+/-0.02	0.90+/-0.02	
	ρ	0.9+/-0.05	0.85+/-0.05	
	ε_h	0.77+/-0.01	0.77+/-0.01	
Center of pressure	CP stays within a 10mm (TBR) radius circle about the centroid			Control the length of the moment arm
Temperature gradient	ΔT (temperature differential between sun and shade sides) $\leq 5°$ C (TBR) over a spin period			Control thermal radiation torque, jitter
Solar cell location/operation	Maintain symmetry about the spin axis. Arrange solar cell strand to allow symmetry of operational/non-operational cells about the spin axis			Minimize unwanted imbalance torque. Accommodate optical property change for operational and non-operational cells

Derived Requirements (2 of 14)
Sun Shield Design (2 of 2)

Propulsion Deck Panel Requirements

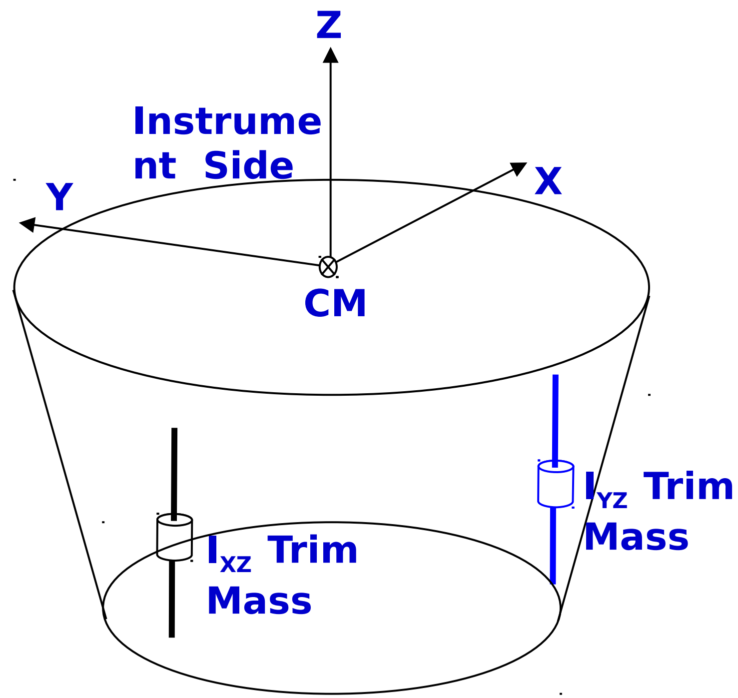
Items	Requirements			Rationale/Remarks
Quantity	One (1)			
Installation angle errors	Pitch angle error: ±0.1 (TBR) deg Radial angle error: ±0.1 (TBR) deg			Limited by solar precession, sun angle, and spin rate variation requirements
Flatness	Less than 5 mm over 2 m length			Accommodate manufacturing and installation errors, thermal deformation
Surface area	$0.74 \pm 0.01\ m^2$ (per panel)			Provide control torque for solar precession.
Optical properties (Al Kapton)		BOL	EOL	Sunside: Aluminized Kapton Shadeside: unspecified, EOL: 5 years at GEO Ca = solar absorptivity, ρ = Cs/(Cs+Cd) ε_h = hemispherical emissivity
	Ca	0.88+/-0.02	0.90+/-0.02	
	ρ	0.9+/-0.05	0.85+/-0.05	
	ε_h	0.77+/-0.01	0.77+/-0.01	
Center of pressure	CP stays within a 8 mm (TBR) radius circle about the centroid			Control the length of the moment arm
Temperature gradient	ΔT (temperature differential between sun and shade sides) ≤ 5°C (TBR) over a spin period			Control thermal radiation torque, jitter

Electronics Deck Panel Requirements

Items	Requirements	Rationale/Remarks
Quantity	Three (3)	
Deployment angle errors	Pitch angle error: ±0.1 (TBR) deg Radial angle error: ±0.1 (TBR) deg Clocking angle error: ±0.1 (TBR) deg	Limited by solar precession, sun angle, and spin rate variation requirements
Flatness	Less than 5 mm over 2 m length	Accommodate manufacturing and installation errors, thermal deformation

Derived Requirements (3 of 14)
Trim Mass System

Trim mass ID	Mass (kg)	Stroke (m)	Null trim mass position from CM ([X,Y,Z], m)	Capability	Remarks
I_{XZ}	3	+/- 0.23	[-0.48,0,-0.38]	ΔI_{XZ} of 0.33 kg-m^2	Spin axis misalignment correction
I_{YZ}	3	+/- 0.23	[0,-0.48,-0.38]	ΔI_{YZ} of 0.33kg-m^2	



Items	Requirements	Rationale/Remarks
Assembly and deployment angle errors (composite)	0.1 (TBR) deg or less	
Position error at the center of travel	1 mm or less	
Stroke resolution	$\leq$0.5 mm	Accommodate required spin axis alignment requirement of 30 as

Derived Requirements (4 of 14)
Trim Tab System

Items	Requirements	Rationale/Remarks
Quantity and location	Three (3), located 120 deg apart along the circumference of the electronics deck	Individual tab size for stowage, placement consideration with trim areas
Degrees of freedom	One (1), pitching up and down with respect to the deck	
Assembly and deployment angle errors (composite)	Pitch angle error: $\pm$0.1 (TBR) deg Radial angle error: $\pm$0.1 (TBR) deg Clocking angle error: $\pm$0.1 (TBR) deg	Limited by solar precession, sun angle, and spin rate variation requirements
Flatness prior to integration	5 mm or less over 2 meters	Same as solar array flatness
Angular travel range	$-40 \le \gamma \le 40$ (deg)	Sun angle of 35$\pm$5 deg limits the trim tab effectiveness. Nominal position at 0 deg.
Angular resolution	$\le$0.5 deg	Accommodate allowable ranges of spin axis inertia, spin rate, precession rate, sun angle, optical properties
Minimum surface area	0.25 m^2 (384 in^2, 16” by 24” rectangle, longer dimension attached to the deck)	Provide enough control authority for precession rate control
Optical properties	— BOL — EOL Ca — 0.1 — 0.27 ρ — 0.92 — 0.88 e — 0.76 — 0.76	Sunside: Ag FEP with ITO coating Shadeside: unspecified, EOL: 5 years at GEO Ca = solar absorptivity, $\rho = Cs/(Cs+Cd)$ e = hemispherical emissivity
Temperature gradient	ΔT (temperature differential between sun and shade sides) $\le 5^\circ$ C (TBR) over a spin period with 40 pitch angle	Control thermal radiation torque, jitter
Center of pressure	CP stays within 2 mm radius of the centroid	Control the length of moment arm, due to localized variations of optical properties and geometry

Derived Requirements (5 of 14)
Trim Area System

<table>
<tr><th>Items</th><th colspan="3">Requirements</th><th>Rationale/Remarks</th></tr>
<tr><td>Quantity and location</td><td colspan="3">Three (3) pairs, located 120 deg apart along the circumference of the electronics deck</td><td>Individual area size for stowage, placement consideration with trim tabs</td></tr>
<tr><td>Degrees of freedom</td><td colspan="3">One (1), rotating in and out with respet to the deck</td><td></td></tr>
<tr><td>Assembly and deployment angle errors (composite)</td><td colspan="3">Pitch angle error: $\pm$0.1 (TBR) deg
Radial angle error: $\pm$0.1 (TBR) deg
Clocking angle error: $\pm$0.1 (TBR) deg</td><td>Limited by solar precession, sun angle, and spin rate variation requirements</td></tr>
<tr><td>Flatness prior to integration</td><td colspan="3">5 mm or less over 2 meters</td><td>Same as solar array flatness</td></tr>
<tr><td>Angular travel range</td><td colspan="3">$0 \le \gamma \le 90$ (deg)</td><td>Nominal position at 0 deg</td></tr>
<tr><td>Angular resolution</td><td colspan="3">$\le$0.5 deg</td><td>Accommodate allowable ranges of spin axis inertia, spin rate, precession rate, sun angle, optical properties</td></tr>
<tr><td>Minimum surface area</td><td colspan="3">0.33 m^2 per pair (509 in^2, 18" radius)</td><td>Provide enough control authority for CM-CP offset control</td></tr>
<tr><td rowspan="4">Optical properties</td><td></td><td>BOL</td><td>EOL</td><td rowspan="4">Sunside: Aluminized Kapton
Shadeside: unspecified, EOL: 5 years at GEO
Ca = solar absorptivity, ρ=Cs/(Cs+Cd)
e = hemispherical emissivity</td></tr>
<tr><td>Ca</td><td>0.4</td><td>0.7</td></tr>
<tr><td>ρ</td><td>0.9</td><td>0.8</td></tr>
<tr><td>e</td><td>0.78</td><td>0.78</td></tr>
<tr><td>Temperature gradient</td><td colspan="3">ΔT (temperature differential between sun and shade sides) $\le 5^\circ$C (TBR) over a spin period with 90 rotation angle</td><td>Control thermal radiation torque, jitter</td></tr>
<tr><td>Center of pressure</td><td colspan="3">CP stays within 2 mm radius of the centroid</td><td>Control the length of moment arm, due to localized variations of optical properties and geometry</td></tr>
</table>

Derived Requirements (6 of 14)
Optical Properties

Materials	Requirements			Rationale/Remarks
Ag FEP with ITO coating (trim tabs)		BOL	EOL	BOL: launch + 30 days EOL: 5 years at GEO Ca = solar absorptivity Cs = reflection coefficient, specular Cd = reflection coefficient, diffuse ρ =Cs/(Cs+Cd) ε_h = hemispherical emissivity
	Ca	0.1+/-0.02	0.27+/-0.02	
	ρ	0.92+/-0.05	0.88+/-0.05	
	ε_h	0.76+/-0.01	0.76+/-0.01	
Aluminized Kapton (bus cone MLI, trim areas)		BOL	EOL	
	Ca	0.4+/-0.02	0.7+/-0.02	
	ρ	0.9+/-0.05	0.8+/-0.05	
	ε_h	0.78+/-0.01	0.78+/-0.01	
Solar cells		BOL	EOL	
	Ca	0.88+/-0.02	0.9+/-0.02	
	ρ	0.9+/-0.05	0.85+/-0.05	
	ε_h	0.78+/-0.01	0.78+/-0.01	

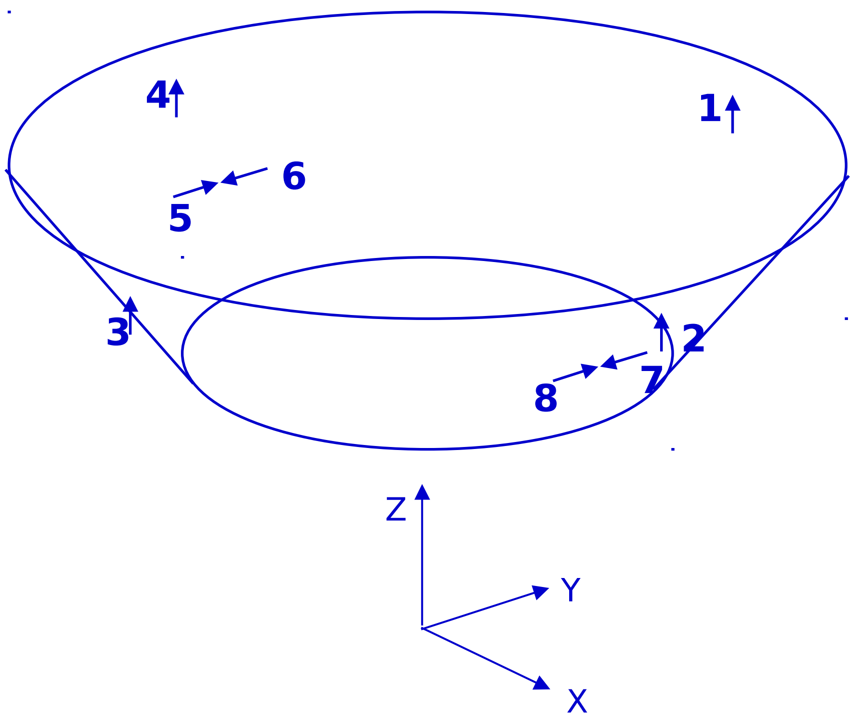
Derived Requirements (7 of 14) Thruster System (1 of 2)

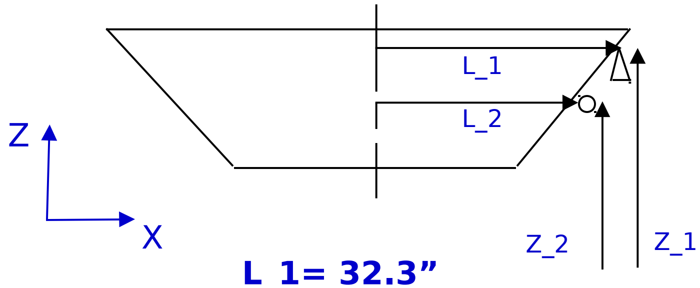
- Full Redundancy for Fault Tolerance in Each Torque Direction Is Not Required
  - Lower Cost & Complexity (i.e. Less Thrusters) More Important Than Redundancy
- Small Thrusters (0.1-1.0 lbf) Required to Minimize Transverse Body Rates for Transition to Science Mode
  - 1.0 lbf More Ideal to Minimize Spin-Up/Down Time for AKM Burn
- Larger Thrusters (5lbf-10 lbf) Required to Damp Nutation During Fast-Spin Phase (Pre/Post AKM Firing)
- Cost Considerations or In-House Availability Lead to Preference for Combination of 0.2-lbf & 5-lbf Thruster Sizes
  - Analysis of Various Thruster Control Modes Verifies Requirements Met
    - 0.2-lbf Jets Yield Low Body Rates for Transition to Science Mode
    - 5-lbf Jets Provide Adequate Active Nutation Control Capability
- Thruster Alignment/Knowledge
  - 0.2-lbf: 1.0 deg/ 0.1 deg
  - 5.0-lbf: 0.5 deg/ 0.1 deg
- Thrust Magnitude Matching: Require Spin-Up Jets to Be Matched Within 2%

Derived Requirements (7 of 14)
Thruster System (2 of 2)

Thruster Sizing
1,3: 5 lbf
2,4,5-8: 0.22 lbf

ID	Thrust unit vecto		
	x	y	z
1	0	0	1
2	0	0	1
3	0	0	1
4	0	0	1
5	0	1	0
6	0	-1	0
7	0	-1	0
8	0	1	0





L_1= 32.3”
Z_1= 72”
L_2= 27.3”
Z_2= 65.5”

Zc.m. w/AKM= 58”
Zc.m. w/dry AKM= 73”
Zc.m. w/o AKM/interstage= 81.4”

First Acquisition Error Allocation

- **Initial On-Orbit Acquisition 0.11 Deg x 0.11 Deg Search Area (5 x 5 Array Of Acquisition Windows) (3σ)**
  - *ST To Instrument Error*: Star Tracker Alignment Cube to Instrument Primary Alignment Cube Knowledge and Stability ± 0.037 Deg (± 640 μradians)
    - Bias
      - Mechanical Shift (1) ± 150 μradians — *Due to Launch & Ascent Loads*
      - Thermal Effects ± 300 μradians
        - Distortion of Star Tracker Bracket (2) ± 150 μradians — *CTE & Gradients*
        - Distortion of Instrument Deck (2) ± 150 μradians — *CTE & Gradients*
      - Moisture Outgassing (2) ± 150 μradians — *From Composite Structures*
    - Random
      - Measurement Error ± 40 μradians — *Measurement Accuracy & Repeatability*
  - *Attitude Measurement Error*: Star Tracker Internal Axes to Star Tracker Alignment Cube Stability ± 0.037 Deg (± 640 μradians)
    - Attitude Estimation Error ± 0.037 Deg (± 640 μradians)
  - *Instrument Error*: Instrument Primary Alignment Cube to Instrument Optical Axis Knowledge and Stability ± 0.037 Deg (± 640 μradians)
    - Bias
      - Mechanical Shift ± 150 μradians — *Due to Launch & Ascent Loads*
      - Thermal Effects (2) ± 300 μradians — *CTE & Gradients*
      - Moisture Outgassing (2) ± 150 μradians — *From Composite Structures*
    - Random
      - Measurement Error ± 40 μradians — *Measurement Accuracy & Repeatability*

(1) Can Determine Order of Magnitude From Pre/Post Environmental Test Alignment Measure
(2) Estimate of Effect can be Determined From Modeling/Analysis
(3) Acquisition Window is 600 x 600 pixels

Derived Requirements (9 of 14)
Re-Acquisition Error Allocation

- **Re-Acquisition** 600 x 600 Pixel Window ±390 μradians (±80 arc-sec) (3σ)
  - **Observatory Attitude Estimation** ± 270 μradians
    - **Propagation Of Attitude From Rate Estimate For Instrument** ± 25 μradians (TBR)
      For Targeting Acquisition Window
    - **Attitude Estimation via Kalman Filter** ± 245 μradians
      - **Star Tracker Attitude Updates** 225 μradians (TBR)
        ST Spec
      - **5 msec Timing Error (ST To FSC)** 20 μradians (TBR)
        S/W Spec
      - **IMU Attitude Propagation** Negligible (2)
        IMU Spec
  - **Star Tracker Axes to Instrument Optical Axis Knowledge and Stability** ± 120 μradians
    - **On-Orbit Alignment Knowledge** ± 25 μradians (TBR)
      Updated From Ground Weekly
    - **Shift From Last Alignment Update** 115 μradians
      - **Thermal Effects (1)** 110 μradians (TBR)
        CTE & Gradients
      - **Moisture Outgassing** 5 μradians (TBR)
        From Composite Structures

(1) Estimate of Effect can be Determined From Modeling/Analysis
(2) Assumes that at least one ST is providing updates when re-acquisition

Derived Requirements (10 of 14)
AKM & High Spin Rate Modes

	Description	Units	Requirement (Max. Allowable)
1	Thruster Force Level Matching For Spin-Up/Down Jet Pairs (5 & 7, 6 & 8)	%	2 (TBR)
2	Thruster Alignment For Spin-Up/Down Jet Pairs (5 & 7, 6 & 8)	deg	1.0 (TBR)
3	Axial (Z-axis) Offset Of Each Of Jets 5 Through 8 With Respect To The Plane Of The Thrusters	in	0.25 (TBR)
4	AKM Mounting Flange To FAME Coordinate System Angular Misalignment	deg	0.03 (TBR)
5	AKM Mounting Flange To FAME Coordinate System Radial Offset	in	0.01 (TBR)
6	Principal Axis Misalignment Of Full Flight Configuration ($Z_{principal}$ w.r.t. $Z_{geometric}$)	deg	0.5 (TBR)
7	Spin Rate Required During AKM Burn	rpm	60 (TBR)

Derived Requirements (11 of 14)

Sensor Processing (1 of 2)

Mode	Support Function	Control/Knowledge Parameter	Control Requirement	Knowledge Requirement	Knowledge Comments
Closed Loop Spin Rate Control	On-Orbit Balance	Spin Rate (Corresponding To 40 Min & 20 Min Spin Periods)	+/-500 μrad/sec	+/-50 μrad/sec	ST, IMU, KF Derived Requirements
Inertial Pointing	Normal Mode Acquisition	Spin Rate (1)	+/-262 μrad/sec	+/-30 μrad/sec	SSS, ST, IMU, KF Derived Requirements
		Transverse Rate (2)	+/-[30] μrad/sec	+/-[30] μrad/sec	
		Sun Angle	+/-5 Deg	+/-0.5 Deg	
Normal - Active Control Operation	Spin Rate Control	Spin Rate (1)	+/-30 μrad/sec	+/-3 μrad/sec	ST, IMU, KF Derived Requirements
	Precession Rate Control	Transverse Rates (2)	+/-5 μrad/sec	+/-1 μrad/sec	
	Sun Angle Variation	Sun Angle	+/-1 Deg	+/-0.5 Deg	SSS Derived Requirement
Normal - Passive Operation	Spin Rate Variation	Spin Rate (1)	+/-0.262 μrad/sec	+/-0.03 μrad/sec	Instrument Derived Requirement (ADCS Capabilty: +/-1 μrad/sec)
	Precession Rate Variation	Transverse Rates (2)	+/-5 μrad/sec	+/-1 μrad/sec	ST, IMU, KF Derived Requirements
	Sun Angle Variation	Sun Angle	+/-5 Deg	+/-0.5 Deg	SSS Derived Requirement
	Instrument Attitude Acquisition	Attitude	N/A	+/-250 μrad/axis	ST, IMU, KF Derived Requirement
		Rate (3)	N/A	+/-[5] μrad/sec	

(1) Nominal Spin Rate Of 262 mrad/sec
(2) Nominal Precession Rate Of 3.64 μrad/sec (Rotation Of Spin Axis About Sun Line)
(3) From Nominal For Applicable Axis
[X] Indicates Value To Be Resolved (TBR)

Derived Requirements (12 of 14)
Sensor Processing (2 of 2)

Mode	Support Function	Control/Knowledge Parameter	Control Requirement	Knowledge Requirement	Knowledge Comments
Inertial Pointing	AKM Spin-Up Initialization	AKM Burn Vector & Roll Angle	+/- 1 Deg	+/- 0.1 Deg	SSS, ST, IMU, KF Derived Requirements
	Orbit Adjustment Burns	Attitude	+/- 0.5 Deg	+/- 0.05 Deg	ST, IMU, KF Derived Requirements
Closed Loop Spin Rate Control	Control Of Spin Rate	Spin Rate	+/- 100 mrad/sec	+/- 50 mrad/sec	IMU Derived Requirements
Active Nutation Control	Control Of Nutation Angle	Nutation Angle	+/- 0.25 Deg	+/- 0.1 Deg	IMU & Inertia Derived Requirements
Spin Axis Precession	Pointing To AKM Burn Vector	Spin Axis Orientation & Roll Angle	+/- 1 Deg	+/- 0.5 Deg	SSS Sun Angle, SSS Roll Angle Update, KF Initialization, IMU Propagation Derived Requirements
Safe Hold	Pointing To Sun Vector	Sun Angle	+/- 20 Deg	+/- 10 Deg	CSS Derived Requirements

Derived Requirements (13 of 14)
Along Scan Allocations

Error Sources	Error Budget, mas/s (Total Allocated: 54 mas/s over 300 sec, RSS)	Remarks
(A) Gravity Gradient Torque	30	Controlled By Transverse Axis MOI Difference And The Orientation Of Spin Axis With Respect To The Local Vertical
(B) Magnetic Torque	5 (TBR)	Controlled By S/C Residual Dipole Moment In X And Y Axes (<200 Pole-Cm) And Earth Magnetic Field At GEO
(C) Variation In Solar Pressure	5 (TBR)	SOHO Model, Random, Seasonal Variations
(D) Sun Shield Optical Property Variation	20 (TBR)	
(E) Sun Shield Deployment /Geometry Error	20 (TBR)	
(F) Thermal Radiation	20 (TBR)	
(G) CM-CP Offset (Radial)	20 (TBR)	
(i) Others (TBD)	20 (TBR)	

Derived Requirements (14 of 14)
Cross Scan Allocations

Error Sources		Error Budget (pixels)	Remarks
Precession (Total: 6.5 Pixels, Sum of (A) and RSS (B) Thru (L))	(A) Expected Precession (Steady State)	3.6	Corresponds to 18 Day Precession Period
	(B) Variation In Solar Pressure	0.25 (TBR)	SOHO Model, RSS (B) Through (I) = 2.84
	(C) Gravity Gradient Torque	1.25	
	(D) Magnetic Torque	0.25	S/C Residual Dipole In Z-Axis < 500 pole-cm
	(E) Nutation	1.0	Corresponds to 30 As Nutation Angle, Residual Of Initial Nutation
	(F) Sun Shield Optical Property Variation	1.0 (TBR)	
	(G) Sun Shield Geometry Error	1.0 (TBR)	Surface Flatness, Potato Chipping
	(H) Sun Shield Thermal Radiation	0.75 (TBR)	
	(I) CM-CP Offset (Axial)	1.0 (TBR)	
	(J) Instrument Thermal Radiation	1.0 (TBR)	Instrument Radiators, Apertures
	(K) Sun Angle Variation	0.5	35+/-5 deg
	(L) Earth Albedo	0.75 (TBR)	
Alignment Errors (Total: 3 Pixels, Sum)	Spin Axis Alignment	0.75	Corresponds to 30 as Spin Axis Misalignment
	CCD to FPA	2.0	

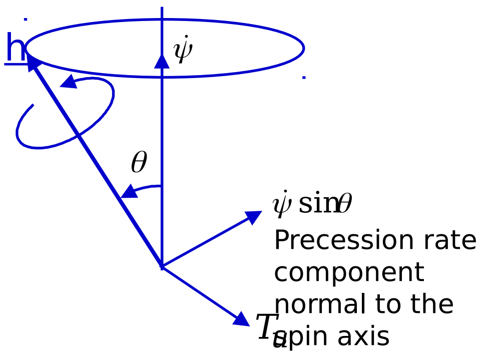
Solar Precession Design

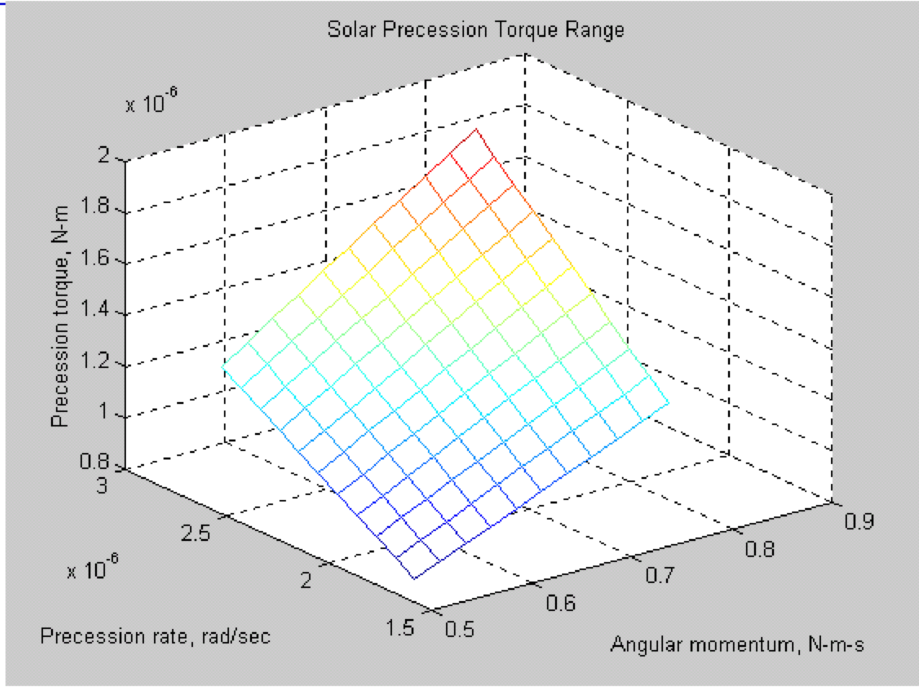
Precession Torque Range

- **Spin Axis Inertia (kg-m²): 216 $\le I_s \le$ 264 (240 $\pm$ 10%)**
- **Spin Period (min): 40 $\pm$ 4**
- **Angular Momentum Range (N-m-s): 0.51 $\le h_s \le$ 0.77**

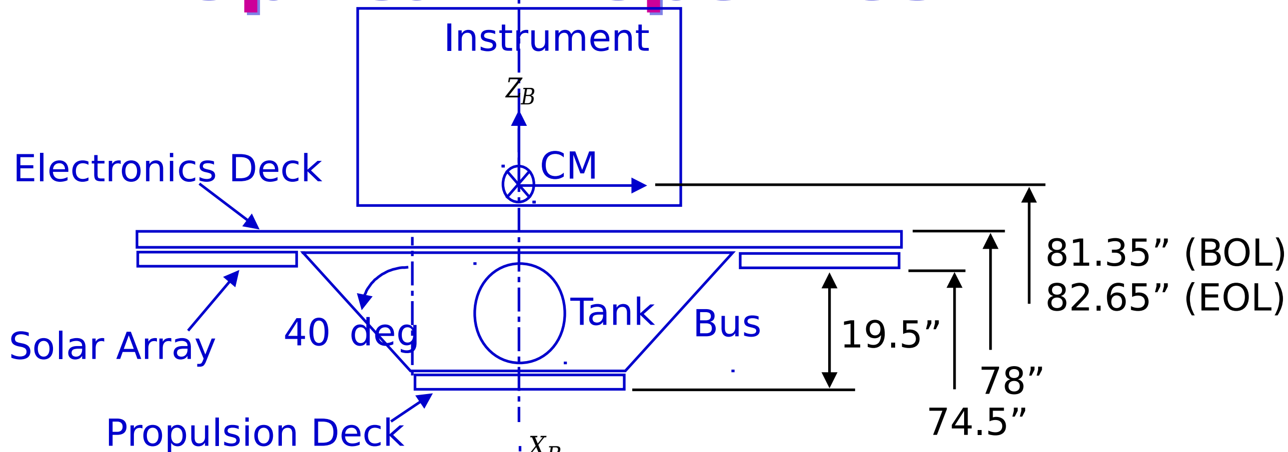
- **Precession Period (Days): 20 $\pm$ 2**
- **Sun Angle (deg): 35 $\pm$ 5**
- **Precession Rate Range (μrad/sec): 1.65 $\le \dot{\psi}_n \le$ 2.60**

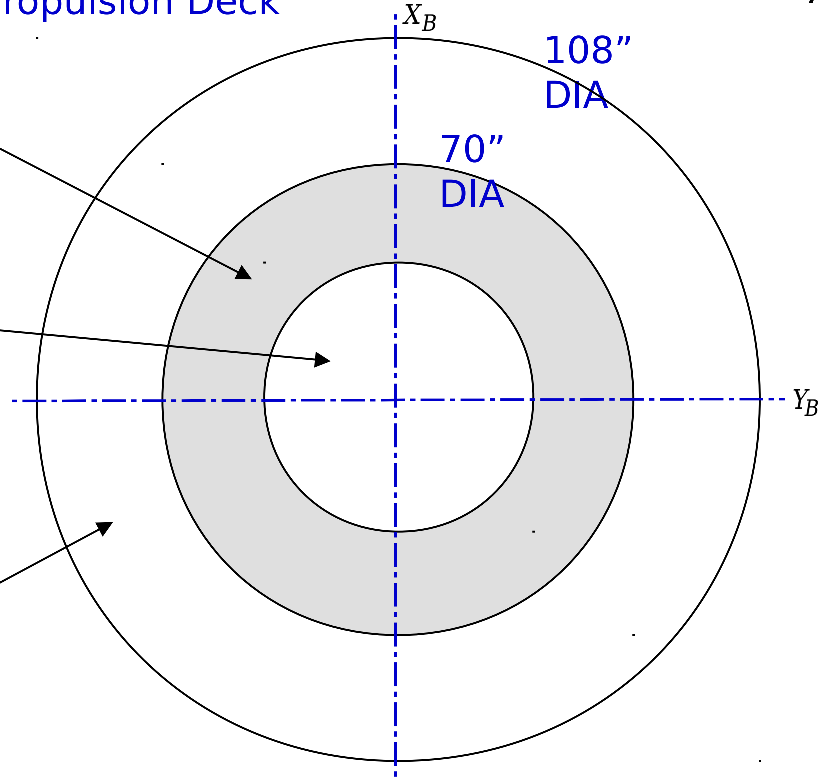
- **Nominal Precession Torque (μN-m): 1.31**
- **Precession Torque Range (μN-m):**
  0.85 $\le T_u \le$ 1.99 or T_u = 1.42 $\pm$ 0.57





Sun Shield Geometry / Optical Properties





Side wall

Propulsion deck:
D = 38” (0.97m)

Solar Panel: Solar cells
Ca = 0.88-0.90 (BOL-EOL)
ρ= 0.9-0.85 (BOL-EOL)
e=0.77-0.77 (BOL-EOL)

Candidate coatings for the cone (p-deck and side wall):
Ag FEP with ITO
Ca = 0.1-0.27 (BOL-EOL)
ρ = 0.92-0.88 (BOL-EOL)
e=0.76-0.76 (BOL-EOL)
Black Kapton (MLI)
Ca = 0.92-0.94 (BOL-EOL)
ρ = 0.5-0.0 (BOL-EOL)
e=0.82-0.82 (BOL-EOL)
Aluminized Kapton (MLI)
Ca = 0.4-0.7 (BOL-EOL)
ρ = 0.9-0.8 (BOL-EOL)
e=0.78-0.78 (BOL-EOL)

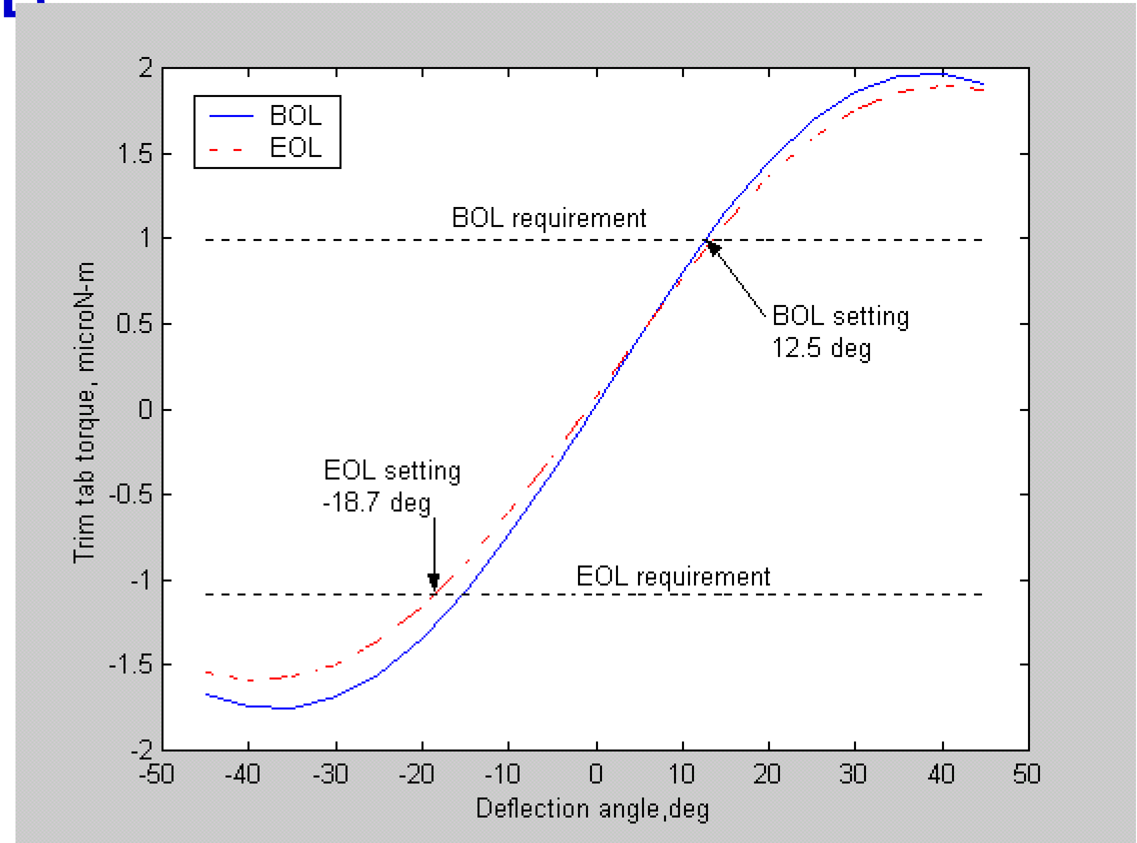
Precession Torque Requirements

- **Accommodate:**
  - **BOL and EOL Optical Properties**
  - **Axial CM Offset (BOL to EOL)**
  - **Thermal Radiation Torque**
  - **Spin Rate Variation**
  - **Precession Rate Variation**
  - **Sun Angle Variation**
  - **Spin Inertia Variation**
- **Most Favorable Trim Torque Range for Solar Precession:**
  - **0.99 (BOL) to -1.08 (EOL) With Al Kapton**

Torque (Tu, 1e-6 N-m)	BOL	EOL	BOL	EOL	BOL	EOL	Remarks
Exterior coating of the cone	Black Kapton		Silver Teflon		Al Kapton		
Axial CM distance from solar array	6.85 in	8.15 in	6.85 in	8.15 in	6.85 in	8.15 in	Due to tank depletion
Solar panel	1.13	1.38	1.12	1.38	1.12	1.38	
Side wall	-0.13	0.03	-0.74	-0.46	-0.52	-0.15	
Top panel	1	1.09	0.18	0.39	0.48	0.83	
Total solar radiation torque	2	2.5	0.56	1.31	1.08	2.06	
Solar panel	-0.01	0	0	0	0	0	
Side wall	-0.2	-0.18	-0.02	-0.05	-0.08	-0.13	
Top panel	0	0	0	0	0	0	
Total thermal radiation torque	-0.21	-0.18	-0.02	-0.05	-0.08	-0.13	
Solar panel	1.12	1.38	1.12	1.38	1.12	1.38	
Side wall	-0.33	-0.15	-0.76	-0.51	-0.6	-0.28	
Top panel	1	1.09	0.18	0.39	0.48	0.83	
Total solar and thermal radiation torque	1.79	2.32	0.54	1.26	1	1.93	
Precession torque needed	**1.42**	**1.42**	**1.42**	**1.42**	**1.42**	**1.42**	
Trim torque needed:							
Solar radiation only case	-0.58	-1.08	0.86	0.11	0.34	-0.64	
Solar + thermal radiation case	-0.37	-0.9	0.88	0.16	0.42	-0.51	
Trim torque needed for inertia, spin and precession rates, sun angle variation (+/- 0.57)							
Solar radiation only case (min)	-1.15	-1.65	0.29	-0.46	-0.23	-1.21	
Solar radiation only case (max)	-0.01	-0.51	1.43	0.68	0.91	-0.07	
Solar + thermal radiation case (min)	**-0.94**	**-1.47**	**0.31**	**-0.41**	**-0.15**	**-1.08**	
Solar + thermal radiation case (max)	**0.20**	**-0.33**	**1.45**	**0.73**	**0.99**	**0.06**	

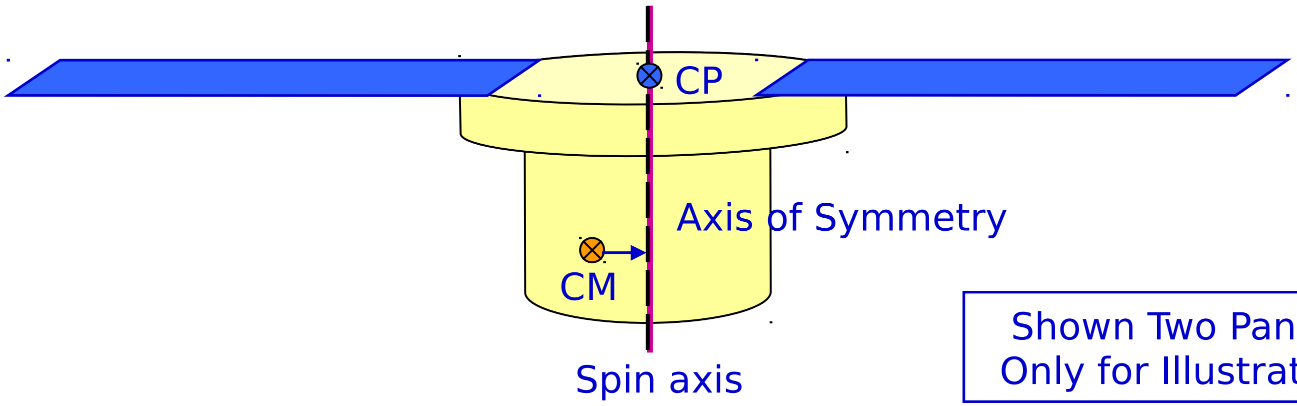
Trim Tab Sizing for Precession Control

- **Control Torque Requirement (Tu, 10-6 N-m):**
  - **0.99 (BOL) to -1.08 (EOL)**
- **Trim Tab Specification:**
  - **3 Total, 120 Deg Apart**
  - **Ag FEP Coating**
  - **16” by 24” (384 in2 or 0.25 m2) Rectangle, Longer Dimension Attached to the Panel**
- **Trim Tab Settings:**
  - **12.5 deg BOL**
  - **-18.8 deg EOL**
- **Torque Margins:**
  - **BOL: 0.89e-6 N-m**
  - **EOL: 0.51e-6 N-m**



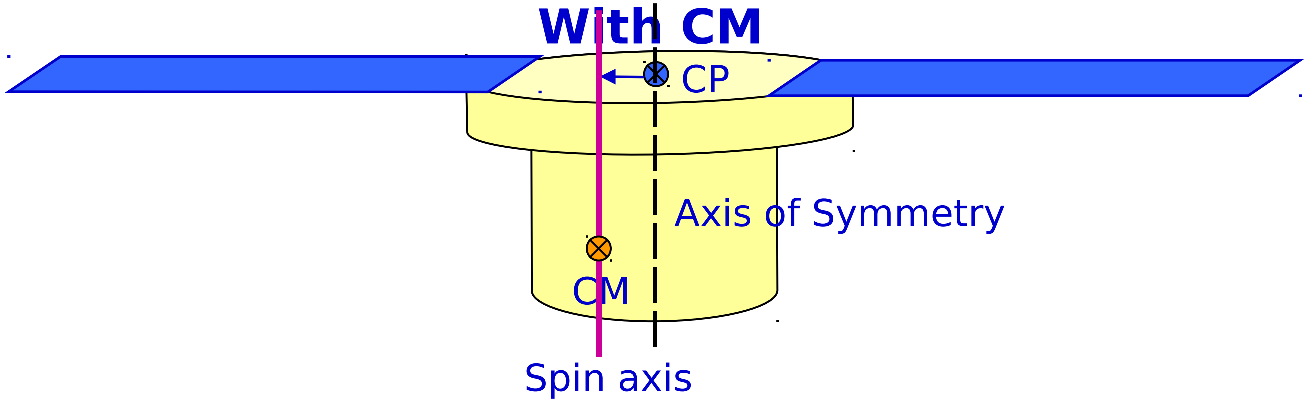
CP-CM Offset Control Concept

CM (Center of Mass) Control: Move CM to Align With CP



Shown Two Panels Only for Illustration

CP (Center of Pressure) Control: Move CP to Align With CM



CM-CP Offset Correction Torque Requirements

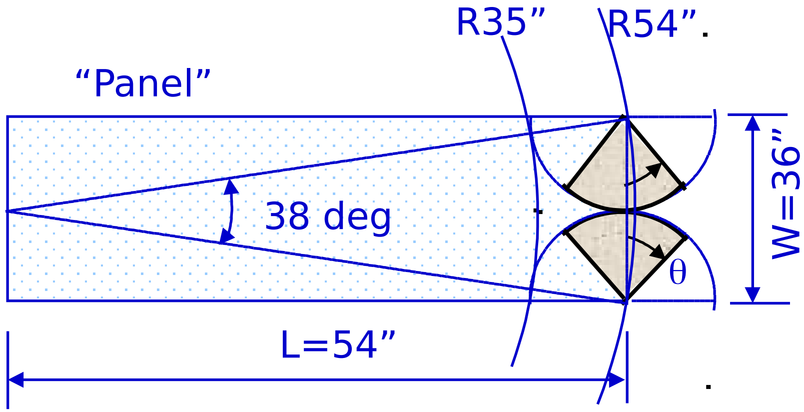
- **Accommodate:**
  - **BOL and EOL Optical Properties**
  - **Axial CM Offset (BOL to EOL)**
  - **Radial CM-CP Offset: 20 mm Maximum**
  - **Thermal Radiation Torque**

- **Torque Magnitude Needed for CM-CP Offset Correction**
  - **Tu (Precession Torque, mN-m): 0.61 (BOL) to 0.63 (EOL)**
  - **Tw (Precession Torque, mN-m): 0.27 (BOL) to 0.29 (EOL)**

	Torque (Tu, 1e-6 N-m)		Torque (Tu, 1e-6 N-m)		|δTu| (1e-6 N-m)		|δTw| (1e-6 N-m)	
	BOL	EOL	BOL	EOL	BOL	EOL	BOL	EOL
Exterior coating of the cone	Al Kapton							
Axial CM-CP distance (m)	0.17	0.21	0.17	0.21	0.17	0.21	0.17	0.21
Radial CM-CP distance (m)	0	0	0.02	0.02	0.02	0.02	0.02	0.02
Solar panel	1.12	1.38	0.78	1.04	0.34	0.34	0.13	0.13
Side wall	-0.6	-0.28	-0.41	-0.07	0.19	0.21	0.13	0.14
Top panel	0.48	0.83	0.4	0.75	0.08	0.08	0.014	0.024
Total solar and thermal radiation torque	1	1.93	0.77	1.72	**0.61**	**0.63**	**0.274**	**0.294**

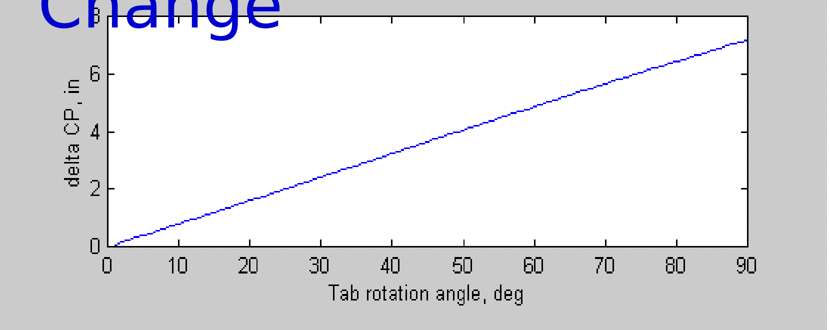
Trim Area Sizing for CP- CM Offset Control

- **Trim Area Specification:**
  - **3 Sets Total, 120 deg apart**
  - **Al Kapton Coating**
  - **A Pair of Quarter Circles of 18” Radius**



Function	Rotating Tabs (a pair as a unit)
Area adjustment	$\frac{W^2\theta}{4}$
Corresponding CP change of the tab	$\frac{W(1-\cos\theta)}{3\theta}$
Corresponding CP change of the panel	$\frac{\frac{WL^2}{2}+\frac{W^2\theta}{4}\left[L+\frac{W(1-\cos\theta)}{3\theta}\right]}{WL+\frac{W^2\theta}{4}}-\frac{L}{2}$

Panel CP Change



- **Simulation Indicates Max. Sun Shield CP Change Is About 40% of the Maximum Panel CP Change., That Is 2.8 Inch or 71 Mm**
- **Coordination of Three Area Tabs Produces About 2.5 Inch or 60 Mm Sun Shield CP Offset in Any Direction, Meeting the 20 Mm Requirements**
- **Area Tab Size Can Be Increased, If Needed**